

# AGENCY DRAFT CORRECTIVE MEASURES STUDY WORK PLAN

Former Rhone-Poulenc Site

Tukwila, Washington

Prepared for:

# **Container Properties**

Kent, Washington

Prepared by:

# **AMEC Environment & Infrastructure, Inc.**

600 University Street, Suite 600 Seattle, Washington 98101 (206) 342-1760

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#### **ACRONYM LIST**

μg/kg micrograms per kilogram
μg/L micrograms per liter
bgs below ground surface
Boeing The Boeing Company

CERCLA Comprehensive Environmental Response, Compensation, and Liability Act

cm centimeters

CMS Corrective Measures Study

CO<sub>2</sub> carbon dioxide

COCs contaminants of concern ENR enhanced natural recovery

EPA Environmental Protection Agency
HCIM Hydraulic Control Interim Measure

ICs institutional controls
mg/kg milligrams per kilogram
mg/L milligrams per liter

MNA monitored natural attenuation
Monsanto Monsanto Chemical Company

NPDES National Pollutant Discharge Elimination System

NPL National Priorities List

ORC® oxygen releasing compounds

Order Administrative Order on Consent No. 1091-11-20-3008(h)

PCBs polychlorinated biphenyls
PMP Performance Monitoring Plan
PRB permeable reactive barrier
PRGs Preliminary Remediation Goals
QA/QC quality assurance/quality control

RCRA Resource Conservation and Recovery Act

RFI RCRA Facility Investigation

SVE soil vapor extraction

SVOC semivolatile organic compound TPH total petroleum hydrocarbons VOC volatile organic compound

WAC Washington Administrative Code



# CORRECTIVE MEASURES STUDY WORK PLAN

Former Rhone-Poulenc Facility
Tukwila, Washington

#### 1.0 INTRODUCTION AND PURPOSE

The former Rhone-Poulenc facility (site) is located on the Duwamish Waterway at 9229 East Marginal Way South, Tukwila, Washington. This Corrective Measures Study Work Plan (Work Plan) addresses the requirements of Resource Conservation and Recovery Act (RCRA) Administrative Order on Consent (Order) No. 1091-11-20-3008(h) currently applicable to the site. In particular, it documents the scope, objectives, and plan for performing a final Corrective Measures Study (CMS) to identify an appropriate corrective action that will be approved by the U.S. Environmental Protection Agency (EPA). Per EPA's March 17, 2014 letter requesting this deliverable, the Work Plan details how potential corrective action alternatives meet the CMS scope of work in Attachment C of the Order and relevant EPA guidance.

The alternatives evaluated in the CMS must comply with applicable RCRA regulations, State of Washington Dangerous Waste and Solid Waste rules, and EPA guidance for conducting corrective action to at RCRA sites. In particular, the CMS must comply with the following EPA guidance for RCRA Corrective Actions:

- Final Guidance on Completion of Corrective Action Activities at RCRA Facilities (EPA, 2003)
- Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action (EPA, 2004a)
- Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (EPA, 2005a)
- Corrective Action for Solid Waste Management Units at Hazardous Waste Management Facilities (EPA, 1999a)
- Clean and Green Policy, Region 10 Superfund, RCRA, LUST, and Brownfields (EPA, 2009a)
- Principles for Greener Cleanups, Office of Solid Waste and Emergency Response (EPA, 2009b)
- Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 1 Technical Basis for Assessment EPA/600/R-07/139, (EPA, 2007a)



- Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 2
   Assessment for Non-Radionuclides including Arsenic Cadmium, Chromium, Copper, Lead,
   Nickel, Nitrate, Perchlorate, and Selenium EPA/600/R-07/140, (EPA, 2007b)
- Ensuring Effective and Reliable Institutional Controls at RCRA Facilities (EPA, 2007c)
- Institutional Controls: A Site Manager's Guide to Identifying, Evaluating, and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups (EPA, 2000)

The use of green remediation approaches for site corrective action will be considered during the CMS as long as the approaches do not affect use of the property by the current lessee (International Auto Auctions, Inc. or IAAI).

#### 1.1 BACKGROUND

The site occupies approximately 14.4 acres in the city of Tukwila in Seattle's South End Industrial District (Figure 1-1). Historically, the site occupied approximately 25 acres. In 2006, the original site was divided into two separate parcels: the West Parcel (current site) and the East Parcel (6.6 acres). The East Parcel was remediated in 2006–2007 (Geomatrix, 2008a) and later sold to the Museum of Flight Foundation; this property is currently referred to as the Museum of Flight property. A public high school was subsequently constructed on the Museum of Flight property and opened in October 2013. The West Parcel consists of an upland area, a shoreline, and a tideflat that extends into the Duwamish Waterway. Most of the site's upland area is paved; it has been leased since 2007 for temporary storage of wrecked vehicles. The tideflat is composed almost entirely of sediments that are exposed during normal low tides. The West Parcel is currently referred to as the former Rhone-Poulenc site. Figure 1-2 shows the current site layout.

Industrial operations on the original property date back to the 1930s when I.F. Laucks built a pilot plant to formulate glue for use in plywood manufacturing. In 1949, Monsanto Chemical Company (Monsanto) purchased the site and continued the manufacture of glue, as well as paints, resins, and storage of wood preservatives. In 1952, Monsanto commenced vanillin production on the property in addition to previous products. Dry glue and resin production ceased in about 1969. Hardener and extender production stopped in 1970 (PRC, 1990). Vanillin production continued at the site after Monsanto sold the property to Rhone-Poulenc in 1985. Rhone-Poulenc stopped chemical operations in April 1991, and thereafter transferred title to the property to Rhodia, Inc. in January 1998. In November 1998, Rhodia sold the property to Container Properties LLC, the current owner.

The RCRA corrective action process at the site to date has included the initial RCRA Facility Assessment (PRC, 1990) and the RCRA Facility Investigation (RFI) (CH2MHill, 1995). Studies completed subsequent to the RFI include geoprobe and geotechnical investigations listed in Sections 2.3.1 and 2.3.2. Additionally, regular groundwater monitoring has been conducted at the site since



1999. Investigations conducted to support cleanup of the Museum of Flight parcel documented attainment of cleanup standards for that property (Geomatrix, 2006a).

A soil vapor extraction (SVE) interim measure to remove toluene from the subsurface in the area near the former toluene storage tank was completed in 2002. This SVE system operated from October 1999 through November 2002, Approximately 61,300 pounds of toluene removed from the subsurface through January 2002, as detailed in monthly progress reports submitted to EPA by RCI Construction Group.

Container Properties implemented a second interim action, the hydraulic control interim measure (HCIM), to control contaminant migration from the site to the Duwamish Waterway in 2002–2003. HCIM construction was completed in April 2003 and documented in the Hydraulic Control Implementation Report (RCI, 2003). The HCIM included the installation of a subsurface low-permeability barrier wall that surrounds, to the extent practicable, the environmentally impacted upland portion of the site. The area surrounded by the barrier wall is shown on Figure 1-2. The barrier wall is complemented by a system of groundwater extraction wells that pumps groundwater from inside the contained area to establish and maintain an inward-directed groundwater gradient. The recovered groundwater is pretreated in a permitted, on-site treatment system and is discharged to a King County treatment works. A monitoring well network inside and outside the barrier wall has been monitored per the Interim Measures Performance Monitoring Plan (PMP) (AMEC Geomatrix, 2009a). The surface of the site is almost entirely paved with asphalt. The pavement surface, in conjunction with a stormwater drainage system, minimizes infiltration of surface water to the subsurface area enclosed by the barrier wall.

In 2006, Container Properties demolished shallow subsurface and aboveground structures at the site to facilitate redevelopment of the property. Deep, underground structures were left in place. As part of this work, several voluntary interim measures were conducted to remove areas of contamination identified during demolition work (Geomatrix, 2006b, 2007a and b). Soil contaminated with total petroleum hydrocarbons (TPH) near the Transformer A site also was excavated for off-site disposal. Demolition of the cement pad at the former hazardous waste storage area revealed oil-stained soils containing TPH in the oil and diesel ranges. These soils were excavated for off-site disposal. Contaminated soil also was excavated along the northwestern corner of the property to remove soils affected by petroleum, copper, and other contaminants released by apparent historic dumping of materials along the northern property line (Geomatrix, 2007b)

In 2006, Container Properties undertook a voluntary corrective measure on the Museum of Flight property to support property sale and redevelopment. This corrective measure involved excavation and disposal of contaminated soils, primarily copper-affected soils in the shallow fill materials. This



parcel was sold to the Museum of Flight and was removed from the RCRA Order by EPA following successful cleanup (EPA, 2006). Toluene impacts to soil and groundwater were identified on the border between the Museum of Flight and Container Properties parcels, resulting from a toluene release from an underground pipe that had not been drained after Rhone-Poulenc shut down the plant in the early 1990s. The pipe was cut, drained, and a portion was removed during the excavation work. An area of toluene-contaminated soil remains on the Container Properties parcel, and groundwater containing toluene is present in the southwest corner of the Museum of Flight property. A subsequent voluntary corrective measure was undertaken to mitigate this area of toluene-impacted groundwater using SVE and air sparging. Low levels of toluene remain in a small portion of the Museum of Flight property adjacent to the West Parcel (see Figure 1-2); this area is still part of the site and subject to the Order due to the continued occasional exceedance of the toluene preliminary remediation goal (PRG) in groundwater. This area is being treated *in situ* by air sparging and groundwater quality is monitored quarterly.

## 1.2 CORRECTIVE MEASURES AREAS

The HCIM was designed to minimize the migration of site contaminants toward the Duwamish Waterway. It also functions as a containment system for the residual subsurface contaminants of concern (COCs) in this area. The HCIM barrier wall and site setting divides the property into four distinct areas with different potential exposure pathways and/or exposure scenarios. The four corrective measures areas are shown on Figure 1-2 and laid out as follows:

- 1. HCIM Area. This area consists of the portion of the site where soil and groundwater are contained within the barrier wall (see Figure 1-2).
- 2. Uplands Area. This area consists of the small area located between the northern barrier wall and the northern property line and the area between the eastern barrier wall and the east property line with the Museum of Flight (Figure 1-2). This area includes the small portion of the Museum of Flight property with low levels of toluene in groundwater.
- 3. Shoreline Area. This area consists of the strip of shoreline along the Duwamish Waterway and Slip 6, between the barrier wall and the 12-foot mean lower low water contour (Figure 1-2).
- 4. Sediment Area. This area consists of a portion of the tideflat in the Duwamish Waterway within the property boundaries. The tideflat is within the intertidal zone at the base of the shoreline bank below the 12-foot mean lower low water elevation (Figure 1-2). This area is located within the Lower Duwamish Waterway Superfund Site.

The CMS will address the contaminants within these four corrective measures areas that are above applicable PRGs for the site. These PRGs have been provided to the Respondents by EPA.



## 2.0 CURRENT SITE CONDITIONS

The site has been extensively characterized over the last 20 years, pursuant to numerous investigations. This section supplements the 1995 RFI with the more recent data, including characterization of soils, groundwater, and sediments along the shoreline and in submerged lands in the Duwamish Waterway. This section also provides a history of the industrial use of the facility, site hydrogeology, and the distribution of contaminants in soils and groundwater in the HCIM, Uplands, Shoreline, and Sediment Areas.

## 2.1 HISTORICAL SITE USES

Industrial use of the site began in the 1930s. From the late 1930s until 1952, the site was used to formulate glue for use in plywood manufacturing. Paints and resins were manufactured on site, and the wood preservative pentachlorophenol was stored and used. Dry glue and resin production ceased in about 1969. Hardener and extender production stopped in 1970 (PRC, 1990). The processing facilities for these operations were located on the western portion of the site, within the area currently owned by Container Properties (Landau, 1991).

Vanillin production began in 1952 and continued through 1991, when the site was permanently closed (Landau, 1991). The vanillin production facilities were located in the west-central portion of the site, on portions of the site currently owned by both Container Properties and the Museum of Flight. The chemical storage areas were located within a tank farm that was located on the southwest portion of the site. The portion of the site now owned by the Museum of Flight was used primarily for non-manufacturing activities including employee parking. The facility laboratory was located on the property now owned by the Museum of Flight.

Table 2-1 summarizes the chemical compounds historically used, stored or handled at the site. Locations of chemical manufacturing buildings and associated chemical storage and handling areas were documented in the 1990 RCRA Facility Assessment (PRC, 1990), the 1991 Site Assessment (Landau, 1991) and the RFI (CH2M HILL, 1995). Figure 2-1 and Table 2-1 show the documented historical site uses and locations. The above-grade portions of the historical structures and shallow subgrade structures were removed in the 2006 demolition. The historical structures, including known subsurface structures, are shown on Figure 2-1.

#### 2.2 HYDROGEOLOGICAL SETTING

This section summarizes the site hydrostratigraphy and describes current groundwater flow conditions in the HCIM Area (Section 2.2.1), the Uplands Area (Section 2.2.2), the Shoreline Area (Section 2.2.3), and the Sediment Area (Section 2.2.4).



The near-surface hydrostratigraphy at the site is described in the RFI (CH2M HILL, 1995) and was further confirmed during geotechnical investigations conducted by AGI in 2000 (AGI and RCI, 2000) and URS in June 2002 along the proposed alignment of the barrier wall. Five hydrostratigraphic units were identified:

- Unsaturated Zone—The unsaturated zone occurs from ground surface to a depth of about 5 to 11 feet below ground surface (bgs). This zone consists primarily of hydraulic fill with smaller volumes of non-hydraulic construction fill. Low permeability silt and clay strata occur locally at the base of the unsaturated zone, which may cause perching of infiltrating precipitation.
- 2. Upper Aquifer—The Upper Aquifer underlies the unsaturated zone and is continuous beneath the facility. Groundwater in the Upper Aquifer generally occurs under unconfined conditions within the alluvial deposits. The Upper Aquifer is approximately 50 feet thick and is composed of sands and silty sands.
- 3. Upper Aquitard—The Upper Aquitard underlies the Upper Aquifer and is composed of alluvial or glaciomarine silt with scattered traces of fine sand. The Upper Aquitard silt is distinguished from silts in the transitional zone by increased plasticity. The Upper Aquitard ranges in thickness from about 15 to 50 feet, and has an average thickness of approximately 20 feet. The top of the Upper Aquitard ranges in depth from 50 to 75 feet bgs and is deepest near the Duwamish River; the bottom ranges in depth from 75 to 100 feet bgs. The barrier wall is keyed into the Upper Aquitard.
- 4. Lower Aquifer—The Lower Aquifer underlies the Upper Aquitard and occurs in silty, sandy gravel of apparent marine origin. The Lower Aquifer's potentiometric surface is higher than the unconfined Upper Aquifer, indicating a vertical groundwater flow direction upward across the aquitard.
- 5. Lower Aquitard—The Lower Aquitard underlies the Lower Aquifer. The Lower Aquitard is composed of glacial till and weathered sandstone. The thickness of the Lower Aquitard is undefined because work conducted at the site did not penetrate through this unit.

The Unsaturated Zone and the Upper Aquifer are the hydrostratigraphic units that have been affected by contaminants from facility operations.

As noted previously, the site has been divided into four corrective measures areas. Due to the presence of the barrier wall, around the HCIM Area, the four areas, each have a unique hydrogeologic regime. These hydrogeologic conditions for the four corrective measures areas are discussed in Sections 2.2.1 through 2.2.4.

#### 2.2.1 HCIM Area

Current groundwater flow conditions in the HCIM Area differ significantly from those described in the reports prepared before installation of the barrier wall. The low-permeability barrier wall is keyed into the Upper Aquitard, isolating the Upper Aquifer within the barrier wall. Figure 2-2 is a groundwater elevation map for the Upper Aquifer inside the barrier wall, based on data collected during operation



of the HCIM (AMEC, 2014a) Since late February 2004, the mean water level inside the barrier wall, as measured in well MW-49, has been more than 1 foot below the mean water level in the downgradient control well, DM-8, which is located outside of the wall.

Two aquifers underlie the site: the Shallow Aquifer and the Deep Aquifer. The Shallow Aquifer is divided into upper and lower zones. The upper zone of the Shallow Aquifer is defined as the sandier portions of the Shallow Aquifer; it occurs in the depth range of approximately 15 to 40 feet bgs (hereafter referred to as the "Upper Zone"). The lower zone of the Shallow Aquifer is defined as the siltier portions of the Shallow Aquifer; it occurs in the depth range of approximately 45 to 70 feet bgs (hereafter referred to as the "Lower Zone"). The Shallow Aquifer and Deep Aquifer are separated by a low-permeability silt aquitard. The top of the Deep Aquifer is approximately 83 feet bgs.

Tides influence water levels at the site in the Shallow and Deep Aquifers. Water levels in control wells DM-8 and MW-49 (Shallow Aquifer, Upper Zone) for two different time periods are shown in Figures 2-3 and 2-4. The response of water levels to tidal cycles is evident in DM-8, located outside the barrier wall, whereas water levels in MW-49, located inside the barrier wall, remain relatively constant at the time scale of tidal cycles. The U.S. Geological Survey measures river levels upstream of the site, and these upstream water levels do not reflect the water levels in the Duwamish Waterway at Slip 6. Likewise, the tidal water levels measured in Elliott Bay do not reflect the water levels in the Duwamish Waterway, which are also influenced by releases from the upstream reservoir and local precipitation. The water levels measured in DM-8 reflect the groundwater levels influenced by tidal and river stage fluctuations in the Duwamish Waterway.

Water levels in the Deep Aquifer are also tidally influenced. A study conducted from October 15 through December 19, 2007 (the "data gap investigation"), used a network of transducers installed in groundwater monitoring wells to assess tidal influence on groundwater levels, as reported in the Round 38 Performance Monitoring Report (Geomatrix, 2008b). Water levels in wells DM-3A (Upper Zone) and DM-3B (Deep Aquifer) were monitored continuously for a period of two months (Figure 2-5). The groundwater elevations measured in the Deep Aquifer groundwater monitoring well DM-3B were generally 5 to 7 feet higher than the water levels in the shallower groundwater monitoring well DM-3A. The groundwater elevations noted in well DM-3B indicate that the water levels in this well varied with tidal fluctuations.

The presence of the barrier wall and groundwater elevation changes induced by the Duwamish Waterway induce complex groundwater flow directions at the site. Before construction of the barrier wall, groundwater in the Shallow Aquifer flowed across the site from east to west, with a component of the groundwater flow turning south to enter Slip 6. The barrier wall blocks natural groundwater flowing from the east, creating a groundwater mound on the eastern wall and diverting groundwater flow to



the north and south. The northern flow eventually enters the Duwamish Waterway while the southern flow enters Slip 6. Groundwater on the lee side of the barrier wall is dominated by water level fluctuations in the Duwamish Waterway but is expected to be largely stagnant due to the barrier wall. Dissolved COCs in Shoreline Area groundwater are unlikely to migrate from their current location because of minimal convective transport resulting from these stagnant groundwater conditions.

Groundwater recovery from extraction wells within the barrier wall causes groundwater to flow laterally toward the extraction wells, and upward from the Deep Aquifer through the low-permeability aquitard and into the area enclosed by the barrier wall. Water levels within the barrier wall are measured continuously using transducers. The transducer signal is used to control the groundwater extraction rates in the extraction wells to maintain a 1-foot differential water level between the outside and inside of the barrier wall, as measured on the downgradient sides of the wall. The 2013 operations and maintenance (O&M) report (AMEC, 2014a) details the following assessment of water level measurements:

- Groundwater levels at wells inside the wall are similar to each other and fluctuate due to pumping, infiltration, and tidal changes in the Deep Aquifer. The influence of the groundwater extraction system is reflected by the cone of depression seen in the groundwater surface when the pumps are active.
- Groundwater levels in the Shallow Aquifer inside the barrier wall on average are lower than the average water level in DM-8, thereby indicating that an inward-directed horizontal hydraulic gradient has been established.

Vertical upward and downward hydraulic gradients exist between the Upper and Lower Zones of the Shallow Aquifer at the site. Vertical gradients indicate the potential for flow within the same aquifer; however, the groundwater levels in both zones of the aquifer are lower than the average water level outside the barrier wall. Therefore, an inward-directed hydraulic gradient remains so long as this differential water level is maintained. The downward directed vertical gradient in the southwest corner of the barrier wall indicates some uncertainty associated with the local hydrodynamic behavior and flow paths inside the barrier wall in this area.

# 2.2.2 Uplands Area

The Uplands Area includes a strip of land on the eastern (upgradient) side of the HCIM barrier wall, and a strip of land between the northern Container Properties property line and the HCIM barrier wall. Groundwater in both the Upper and Lower Zones of the Shallow Aquifer flows from east to west but is diverted by the barrier wall, resulting in a slight mounding of groundwater along the barrier wall with the flow forced around the wall to both the north and south. The barrier wall on the eastern edge creates a significant damming effect on groundwater along the southeast corner of the barrier wall. The presence of a King County stormwater main that daylights into Slip 6 along the southeast corner



of the property line likely diverts some of this groundwater into Slip 6. Groundwater also flows north and then along the barrier wall, ultimately draining into the Duwamish Waterway. The barrier wall likely results in a stagnant zone of groundwater flow along the eastern (upgradient) side of the barrier wall, although this has not been documented.

#### 2.2.3 Shoreline Area

The Shoreline Area includes the narrow strip of land along the western and southern sides of the HCIM and barrier wall along the Duwamish Waterway and Slip 6. Due to the presence of the barrier wall along the entire Duwamish shoreline of the site, groundwater flow is essentially stagnant as groundwater cannot flow from the HCIM Area outward toward the Duwamish. Rainwater infiltrating into Shoreline Area soils is expected to seep downward to the water table and then flow outward, toward the Duwamish Waterway, affecting only the upper portion of the water table. Tidal changes in the waterway and seasonal river level changes move the stagnant groundwater up and down along this strip. Infiltration in this area is limited to a strip of soil between the barrier wall and the base of the rip-rap at the shoreline.

The shoreline along Slip 6 consists of the strip of land along the southern edge of the barrier wall and The Boeing Company (Boeing) property line. As discussed in Section 2.2.1, the barrier wall configuration at the eastern end of the Slip 6 shoreline results in groundwater entering Slip 6 at the southeast corner of the barrier wall. Slip 6 and the Duwamish tides have a similar stagnating effect on groundwater within the Shoreline Area, and the amount of infiltration is even less than at the shoreline along the Duwamish.

#### 2.2.4 Sediment Area

The Sediment Area of the site is defined as the tideflat along the Duwamish Waterway below 12 feet elevation mean lower low water. As a result, the Sediment Area is located within the zone of daily tidal fluctuations in the waterway. Consequently, groundwater and sediments are significantly affected by the chemistry of the Duwamish Waterway (e.g., salinity). A portion of the Sediment Area is frequently exposed during normal periods of low tide. Groundwater flow from the higher elevations of this tidally influenced area, along the outer edge of the shoreline, are likely affected by the site. Since groundwater in the Shoreline Area is essentially stagnant due to the nearby barrier wall, COCs present in Shoreline Area groundwater are not expected to have significantly affect sediments within the Sediment Area. Groundwater within the tideflat essentially comprises Duwamish Waterway water with limited groundwater input from the Shoreline Area. From a regulatory perspective, all soils within this area are considered sediments.



# 2.3 Previous Investigations

Conditions at the site have been documented in numerous reports of site investigation reports dating back to 1986. Several of the reports contain extensive soil and groundwater analytical data and observations of soil and groundwater conditions; they are the main sources of information for this Work Plan. In addition to these broader investigations, this Work Plan incorporates data from subsequent investigations, including the Sediment Characterization Data Report (AMEC, 2012a), the Shoreline Soil and Groundwater Characterization Data Report (AMEC, 2012b), the West Parcel Redevelopment Report (Geomatrix, 2007a), quarterly and semiannual groundwater monitoring reports, and reports documenting interim removal of polychlorinated biphenyls (PCBs) and copper in soil.

# 2.3.1 Soil and Sediment Investigations

#### 2.3.1.1 Sources of Soil and Sediment Chemical Data

Soil and sediment chemical data were collected as part of the following investigations and cleanup actions:

- Site screening investigation (Dames and Moore, 1986)
- Site assessment (Landau, 1991)
- Final RFI (CH2M HILL, 1995)
- PCB remediation and sewer cleaning (Rhodia, 1998)
- Pre-construction geotechnical investigation (URS, 2002)
- Sediment and porewater investigation (EPA, 2005b) and analyses of split samples collected by Geomatrix Consultants, Inc. (Geomatrix, 2004)
- Pre-demolition investigation (Geomatrix, 2006c)
- Hazardous waste storage and transformer area cleanup (Geomatrix, 2006b)
- Northwest Corner Affected Soil Removal (Geomatrix, 2007b)
- West Parcel redevelopment (Geomatrix, 2007a)
- Sediment characterization (AMEC, 2012a)
- Shoreline soil and groundwater characterization (AMEC, 2012b)



#### 2.3.1.2 Use of Data

Where appropriate, the data from the sources listed in Section 2.3.1.1 were used quantitatively in this Work Plan. The following is an explanation of the degree to which data from each report were used for this Work Plan.

Data Quality: The soil data collected in 1986 (Dames and Moore, 1986) as part of a site assessment for property transfer are not used quantitatively for this CMS. The primary reason for this exclusion is because the report was not available due to proprietary protection. Any historical information from this 1986 document was gleaned from later documents that cited the 1986 report as a reference. AMEC did not have access to the analytical laboratory sheets to independently verify the accuracy of the reported data. The RFI Work Plan (CH2M HILL, 1993) also cited a number of reasons for not using data from the 1986 Dames and Moore report, including that the number of samples and analyses were limited and not representative; the Dames and Moore soil samples were composited from a wide area, resulting in less precise contamination characterizations; and the quality control was less comprehensive than in more recent investigations. The RFI Work Plan also noted that the data were seven years old in 1993 and were not representative of current conditions for the volatile and other non-persistent chemicals. The Dames and Moore data were intended to be used qualitatively to evaluate areas of the site if no other data were available, and to corroborate identified impacted areas.

The RCRA Facility Assessment (PRC, 1990) was conducted to identify solid waste management units, and historic environmental release pathways. The 1990 assessment built on the Dames and Moore 1986 site assessment report and information provided by Rhone-Poulenc; no independent sampling or laboratory analysis was conducted for this study. The RCRA Facility Assessment report was used as a reference in this Work Plan for operations history, including process information. This information included locations of underground structures, process chemicals used at the site, and chemical usage and storage locations.

**Data Used Quantitatively:** With the exception of the 1986 Dames and Moore report, soil chemical data from the remaining reports listed in Section 2.3.1.1 were used to summarize current soil contamination, as discussed in Section 3.

The RFI data and all subsequent data were collected under EPA-approved quality assurance/quality control (QA/QC) procedures to provide data of high quality that could be compared to data from previous studies conducted at the site. Compounds detected in associated equipment blanks collected for QA/QC purposes were common laboratory contaminants. Toluene was detected in one equipment blank sample, but at a much lower concentration than the levels being used to assess site conditions. Data validation was performed on all data in accordance with the EPA National Functional



Guidelines for Organic Data Review (EPA, 1991) and Functional Guidelines for Evaluating Inorganic Analysis (EPA, 1988). For parameters not covered in these guidelines, data validation was performed according to the Quality Assurance Project Plan in the approved RFI Work Plan (CH2M HILL, 1993). The RFI data were over 90 percent complete and of high quality.

Analyses conducted during the PCB remediation and sewer cleaning (Rhodia, 1998) involved an EPA-approved field screening test (Method 4020). The QA/QC procedures were followed and described in the report. Sampling methodology followed the New Jersey Department of Environmental Protection Field Sampling Procedures Manual (NJDEP 1992) and/or the RFI Work Plan (CH2M HILL, 1993).

Data included in the Interim Measures Construction Work Plan (URS, 2002) were collected as part of the geotechnical investigation performed in June 2002 for the HCIM. These data were collected under specific QA/QC procedures used in the RFI; consequently, all data from this study were used quantitatively.

Data available from the RFI were limited to those data presented in the main body of the Final RFI Report (CH2MHill, 1995). Only detected constituents were reported for the soil samples collected during the RFI. For this reason, analytical results from the RFI that were below reporting limits could not be used to support delineation of soil contamination at the site.

## 2.3.2 Groundwater Investigations

#### 2.3.2.1 Sources of Groundwater Chemical Data

Groundwater chemical data have been collected at the site historically as part of several investigations and monitoring studies. Chemical data for groundwater were collected as part of the following investigations:

- Site screening investigation (Dames and Moore, 1986)
- Site assessment (Landau, 1991)
- Final RFI (CH2M HILL, 1995)
- HCIM investigation (AGI and RCI, 2000)
- Summer 2001 geoprobe investigation (AGI, 2001)
- 2004–2013 O&M Annual Reports (Geomatrix 2007c, 2008c; AMEC Geomatrix 2009b, 2010; AMEC 2012c, 2012d, 2013a, 2013b, 2014a, 2014b).
- Sediment characterization (AMEC, 2012a)



• Shoreline soil and groundwater characterization (AMEC, 2012b)

In addition to the above investigations, quarterly or semiannual groundwater monitoring has been conducted at the site continuously since 1999. In 2009, the monitoring schedule was changed to semiannually as approved by EPA (AMEC Geomatrix, 2009a).

#### 2.3.2.2 Use of Data

This section explains the degree to which data from each report or source listed in Section 2.3.2.1 were used for this Work Plan.

**Data Quality:** The reports from all of the above investigations contained groundwater data that were used quantitatively in this CMS, except for the following:

- Site assessment (Dames and Moore, 1986)
- Round 5 groundwater sampling by Terra Nova in 1998

Groundwater chemistry data from the 1986 site assessment were not used quantitatively for the same reasons that soil data were not used quantitatively, as described in Section 2.3.1.2.

During review of work being conducted by AGI Risk Assessment in 2000, EPA rejected the Round 5 data, primarily because of quality control issues related to the collection of toluene samples.

**Data Used Quantitatively:** CH2M HILL reviewed the data from the 1991 site assessment (Landau, 1991), and performed validation on a representative group of results (CH2M HILL, 1991). The review found that the data were generally of high quality and acceptable as reported.

The RFI data (CH2M HILL, 1995) and all more recent data were collected under specific QA/QC procedures. A Quality Assurance Project Plan was prepared as part of the approved RFI Work Plan (CH2M HILL, 1993); the Quality Assurance Project Plan was followed for collection and analysis of data for the 1995 and later studies, with the exception of the Round 5 quarterly groundwater monitoring event. Following installation of the HCIM, the groundwater monitoring program scope of work was revised with EPA approval of the 2003 Hydraulic Controls Interim Measures PMP. The PMP has been revised several times since 2003, most recently in 2009, at which time the monitoring was reduced in frequency from quarterly to semiannually (AMEC Geomatrix, 2009a).

Data available from the RFI were limited to those data presented in the main body of the Final RFI Report (CH2MHILL, 1995). Only detected constituents were reported for the groundwater samples collected during the RFI. For this reason, analytical results from the RFI that were below reporting limits could not be used to support delineation of groundwater contamination at the site.



# 2.3.3 Sediment/Porewater Investigations

## 2.3.3.1 Sources of Sediment/Porewater Chemical Data

Sediment and porewater chemical data have been collected at the site as part of various investigations and monitoring studies. However, not all of the chemical data were used quantitatively for this Work Plan. The following list includes all of the reports that contain chemical data for sediment/porewater at the site:

- EPA sediment and porewater investigation (EPA, 2005b) and analysis of split samples collected by Geomatrix Consultants, Inc. (Geomatrix, 2004)
- Sediment characterization (AMEC, 2012a)
- Shoreline soil and groundwater characterization (AMEC, 2012b)

## 2.3.3.2 Use of Data

Data obtained from the reports listed in Section 2.3.3.1 were collected in accordance with an approved QA/QC plan and all reported data were used quantitatively in this CMS.



## 3.0 CONTAMINANTS OF CONCERN AND EXPOSURE PATHWAYS

This section identifies COCs for soils, sediments, and groundwater for each of the four corrective measures areas that make up the site and are addressed by this Work Plan. The COCs are contaminants that exceed the EPA PRGs established for each area.

#### 3.1 Preliminary Remediation Goals

EPA established PRGs for the site in a memorandum dated March 17, 2014 (EPA, 2014). The PRGs address contaminants that have been found in soil, groundwater, and/or sediment at the site. The PRGs reflect current toxicity values consistent with the site physical conditions and the reasonably anticipated potential exposure assumptions for the site. The PRGs are presented in Tables 3-1 through 3-3 and describe briefly below in Sections 3.1.1 through 3.1.3.

#### 3.1.1 Soil PRGs

Soil PRGs were developed to be protective of human health for residential and industrial exposures via ingestion, inhalation, and dermal absorption, as well as to be protective of groundwater. Soil PRGs apply to soils in the HCIM Area, Uplands Area, and Shoreline Area, including soils throughout the vadose zone (upper 11 feet bgs). The soil PRGs are presented in Table 3-1. The soil PRGs for copper (3.55 milligrams per kilogram [mg/kg]) and mercury (0.48 mg/kg) are lower than the natural background concentrations for these constituents in Puget Sound area soil (36.4 mg/kg for copper and 0.07 mg/kg for mercury), which have been determined by the Washington State Department of Ecology (1994).

Uplands and HCIM Area soil PRGs were developed for both unrestricted land use and industrial land use. The industrial use PRGs are based on the assumption that the site remains primarily paved and used for industrial purposes. If future land use changes such that pavement is removed from "all or part of" the property, then the industrial use PRGs may need to be revised. If a given corrective measure cannot achieve the unrestricted PRG, but can achieve a restricted-use PRG, then institutional controls (ICs) may be necessary to restrict future uses of the property. The discussion presented in Section 3.2.1 for soil COCs is based on the assumption that the site will be used for industrial purposes and will remain paved following any corrective measures implemented; therefore, soil COCs were compared to the industrial use PRGs for soil. PRGs for shoreline soils were developed to meet the Washington State Sediment Management Standards to protect sediment as well as terrestrial ecological exposures.

#### 3.1.2 Groundwater PRGs

Groundwater PRGs were developed to be protective of surface water and potable drinking water, following the procedures outlined by EPA (EPA, 2014). The groundwater PRGs protective of surface



water apply to groundwater within the Shoreline Area. The groundwater PRGs protective of drinking water apply to the groundwater samples collected from the HCIM and Uplands Areas. These groundwater PRGs are presented in Table 3-2.

#### 3.1.3 Sediment PRGs

Sediment PRGs were established for COCs presumed to be released from the site to the Sediment Area and that exceed the human health or ecological risk-based levels for the Lower Duwamish Waterway National Superfund site. As the COCs in the tideflats and in-waterway sediments and are not unique to this site, cleanup of the tideflats will be performed as part of the RCRA corrective measures required under the RCRA Order. Any historic contribution the site may have made beyond the property boundaries to the Lower Duwamish Waterway Superfund Site will be managed as part of the remedy for the Lower Duwamish Waterway Superfund site under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Sediment PRGs for the protection of human health and the environment for these contaminants are defined in the EPA's Proposed Plan, Lower Duwamish Waterway Superfund Site (EPA, 2013), and are presented in Table 3-3. As noted in Table 3-3, sediment PRGs may be different for different depth intervals. These sediment PRGs will be used for the portion of the site designated as the Sediment Area.

EPA considers PRGs to represent long term goals; EPA has also established remedial action levels for sediment. *Remedial action levels* RALs are contaminant-specific sediment concentrations that will be used to identify specific areas of sediments that require active remediation (dredging, capping, enhanced natural recovery [ENR], or a combination thereof), taking into consideration the human health and ecological risk reduction that could be achieved by the different remedial technologies. RALS are equal to or higher than the sediment PRGs for each COC and are used only to delineate a site into areas where different remedial technologies would be used (EPA, 2013). Table 3-4 lists the remedial action levels for the sediment COCs at the site.

#### 3.2 CONTAMINANTS OF CONCERN

Site COCs were determined by EPA for compounds that had been detected above applicable PRGs for the HCIM, Uplands, Shoreline, and Sediment Areas. The site has a history of investigations by several different parties that spans more than 20 years. Some borings and/or wells installed by different parties were labeled with similar or identical names. Figures 3-1 and 3-2 indentify the sampling locations associated with each party that has conducted investigations for the site. Figure 3-1 shows the soil sample locations, and Figure 3-2 shows the groundwater sample locations.

In general, soil, sediment, and groundwater at the site have been affected by similar COCs. Figure 3-3 shows general site areas with the highest concentrations of copper in groundwater, toluene in soils and shallow groundwater, and groundwater with elevated pH. Copper, toluene, and caustic



soda were used as process chemicals at the site, and the highest concentrations of these COCs are found in the areas where these chemicals were used and stored. Figure 3-4 shows the vertical distribution of these same COCs along the Shoreline Area, outside the barrier wall.

#### 3.2.1 Contaminants of Concern in Soil and Sediments

The data from previous site investigation reports were compiled in a database with fields for sample location, approximate northing and easting coordinates, sample event, sample date, depth collected, constituent, concentration, qualification flags, units, and matrix. The database was queried for data characterizing site soil and sediment.

The maximum concentrations of each COC at each soil sampling location, regardless of depth, were compared to the EPA PRGs and distribution maps were prepared for COCs that exceeded PRGs in soil samples more than one sampling location. For sediment, the maximum COC result at the two depth intervals with different PRGs were determined and mapped. The resulting COC distributions were mapped as discrete data points for the soil and sediment analyses. Continuity of concentrations between data points is not presumed in light of the heterogeneous nature, variable depths, and sporadic areal distribution of most of the COCs. Appendix A contains the data used for the contamination distribution figures.

The distribution maps generally show the nature and extent of soil and sediment contamination at the site. However, it should be noted that the soil data were acquired more than two decades and therefor represent conditions at the specific time of sample collection only. Significant decreases in COC concentrations have occurred due to interim remedial measures and likely degradation of COCs over time. These reductions in concentration are not depicted on the soil concentration distribution maps. In short, the soil distribution maps are indicative of the most severe conditions that were sampled prior to any interim corrective measures.

#### 3.2.1.1 Summary of Soil and Sediment COCs

This section discusses the distribution in site soils and sediments for each compound for which EPA established a PRG.

## **Organic Compounds**

#### **Toluene**

**Uplands and HCIM:** Large quantities of toluene were used at the site in the production of vanillin from 1952 to 1991. Releases of toluene occurred primarily within the HCIM Area. Soil samples from 11 locations in the HCIM Area exceeded the toluene PRG, and concentrations ranged from 120 mg/kg for a sample collected at location A2-12 at 1.5 feet bgs to 28,000 mg/kg from a sample



collected at location H1 at 2.5 feet bgs. Toluene has been detected in soil samples throughout the vadose zone (Figure 3-5).

In the Uplands Area, during the 2006 site demolition, a 2-inch diameter stainless steel pipe was discovered during cleanup of toluene-affected soil near the current eastern property boundary. This pipe appeared to be the source of toluene in this area of the site, and facility drawings show that it had been connected to the main toluene storage tank that was located within the HCIM Area. Toluene released from this pipe has been the focus of a separate corrective measure on the property, as well as a small strip of the Museum of Flight property. Toluene continues to be detected on the extreme southeast corner of the property at concentrations above the PRG.

**Shoreline:** None of the soil samples collected in the Shoreline Area exceeded the PRG for toluene of 0.670 mg/kg (Figure 3-5).

**Sediments:** Toluene is not a sediment COC listed in EPA's March 17, 2014, PRG memorandum (EPA, 2014).

# Benzene and Ethylbenzene

**Uplands and HCIM:** Benzene and ethylbenzene were detected in soil at concentrations exceeding the PRGs only within the HCIM Area. The exceedances of benzene and ethylbenzene are co-located with toluene exceedances. The two benzene exceedances ranged in concentration from 0.017 to 0.23 mg/kg. Seven ethylbenzene exceedances occurred at concentrations ranging from 0.91 to 6.4 mg/kg. No benzene or ethylbenzene exceedances occurred in soils collected from the Uplands Area (Figure 3-6).

**Shoreline and Sediments:** Benzene and ethylbenzene are not COCs in the Shoreline Area soils or sediment as listed in EPA's March 17, 2014, PRG memorandum (EPA, 2014).

# Total Petroleum Hydrocarbons

**Uplands and HCIM:** Undifferentiated TPH exceeded the PRG in the HCIM Area in a single soil sample (A5-10) from 3–5 feet bgs near the former vanillin black liquor storage area in the southwest corner of the HCIM Area, with a concentration of 8,200 mg/kg (Figure 3-6) (CH2M HILL, 1995). There were no TPH exceedances in the Uplands Area soils.

**Shoreline:** A single exceedance of TPH as diesel occurred in sample SL-01 near the northwest corner with a concentration of 1,000 mg/kg at a depth interval of 0.5–2-feet. TPH as gasoline exceeded the PRG at a concentration of 1,200 mg/kg in the soil sample collected from MW-39 at a



depth of 5 feet bgs. Both of these samples were located near the northwest corner of the site (Figure 3-6).

**Sediments:** TPH is not a Sediment COC listed in EPA's March 17, 2014, PRG memorandum (EPA, 2014).

# Polychlorinated Biphenyls

**Uplands and HCIM:** PCBs were not detected at concentrations in excess of the upland soils PRG in the Uplands or HCIM Areas.

**Shoreline:** The soil samples collected during the shoreline investigation were analyzed for PCBs, but were not analyzed for total organic carbon. The Shoreline Area PRG for total PCBs is 12 mg/kg; in the absence of organic carbon, the appropriate PRG comparison was made to the Puget Sound Apparent Effects Threshold concentration of 130 μg/kg. PCBs in the Shoreline Area exceeded the PRG by greater than 10 times at SL-1. PCBs were also detected above the PRG at SL-2, SL-3, and SL-4 (Figure 3-7).

**Sediments:** Total PCBs were detected in the sediment grab samples collected during the 2011 sediment sampling event (AMEC, 2012a) at concentrations ranging from 12 mg/kg at RP-17 to 1,070 mg/kg at RP-22. All of the sediment samples collected from 0 to 10 centimeters (cm) in depth exceeded the sediment PRG for this depth of 2 mg/kg dry weight. Sediment samples collected as split samples by Geomatrix during the 2004 EPA sediment sampling event from depths ranging from 10 to 45 cm exceeded the PRG of 12 mg per kilogram of organic carbon at SH-01, SH-04, and SH-05 (Figure 3-7) (Geomatrix, 2004). Both SH-04 and SH-05 were located at former stormwater outfall #6.

# Benzyl Alcohol

**Uplands and HCIM:** Benzyl alcohol is not a COC in the Uplands or HCIM Areas.

**Shoreline:** Benzyl alcohol is not a COC in the Shoreline Area.

**Sediments:** Benzyl alcohol is a COC for sediments, and benzyl alcohol was detected at concentrations exceeding the sediment PRG of 57  $\mu$ g/kg at five widely separated sediment sampling locations during the 2011 sediment investigation (Figure 3-8). A sediment investigation performed for Rhodia, Inc showed that benzyl alcohol is present both on-property and off-property upstream of the site at river mile 4.6 to 4.8 (Cardno Entrix, 2012). Benzyl alcohol detections at these locations are widespread, with no discernible hot spots that would be expected if this contaminant was associated with historic releases from the site. The occurrence of benzyl alcohol in an upstream intertidal area suggests that other sources are responsible for the presence of benzyl alcohol in the site sediments.



# Pentachlorophenol

**Uplands and HCIM:** Pentachlorophenol is a COC in the Uplands and HCIM Area soils. The soil PRG for pentachlorophenol is 0.00684 mg/kg, and pentachlorophenol was observed above the PRG in 10 samples collected inside the HCIM Area, two of which had concentrations more than 100 times the PRG (Figure 3-9).

**Shoreline:** Pentachlorophenol is not a COC in the Shoreline Area soils.

Sediments: Pentachlorophenol is not a COC in the Sediment Area.

# Minor Organic Contaminants

Additional organic compounds were identified as COCs. Many of these compounds were detected during past investigations at concentrations exceeding the PRG based on unrestricted land use, but below the cleanup level based on industrial land use. These compounds are not COCs for the shoreline or Lower Duwamish Waterway and were found to be present generally within the area of the toluene plume on the site at the time of the RFI (CH2M HILL, 1995). Distribution maps were not developed for these compounds due to their sparse distribution and based on the assumption that any corrective measure implemented at the site will meet the industrial land use PRGs:

- naphthalene,
- benzo(a)anthracene,
- benzo(a)pyrene
- benzo(b)fluoranthene
- dibenz(a,h)anthracene,
- indeno(1,2,3-cd)pyrene,
- dieldrin; and
- 4,4-DDT.

## **Inorganic Compounds**

#### Arsenic

*Uplands and HCIM:* Among the more than 400 soil samples analyzed for arsenic, only two were found at concentrations exceeding the PRG of 20 mg/kg for Upland and HCIM soils. Both samples A10CS03 and A10MS03 were widely separated in the HCIM Area and contained arsenic concentrations of 52 and 61.4 mg/kg, respectively. Both samples were collected within 1.5 feet of the ground surface (Figure 3-10).



**Shoreline:** None of the vadose zone soil samples collected from the Duwamish and Slip 6 shoreline areas exceeded the shoreline soil PRGs of 14 mg/kg for arsenic. The vadose zone samples collected from the Duwamish and Slip 6 shoreline areas during the 2011 sediment and shoreline investigation (AMEC, 2012a and 2012b) did not have arsenic concentrations greater than 10 mg/kg (Figure 3-10).

**Sediments:** Arsenic was detected at concentrations exceeding the sediment PRG of 7 mg/kg in 22 of the 27 sediment samples collected from the 0- to 10-cm depth interval during the 2011 sediment and shoreline investigation. Similarly, of the nine locations sampled at depths between 0 and 27 cm during the EPA sediment study (EPA, 2005b), arsenic exceeded the PRG at all of the locations for at least one of the depth intervals (Figure 3-10). Arsenic was detected throughout the Duwamish Waterway sediments at an average concentration of 17 mg/kg, and in 93 percent of the sediment samples (AECOM, 2012).

# Copper

*Uplands and HCIM:* Copper was used extensively at the site in the vanillin manufacturing process, primarily as copper sulfate. Copper concentrations in excess of the PRG of 3.55 mg/kg occur throughout the site (Figure 3-11). The majority of the samples exceeding the PRG are located in the HCIM Area with concentrations more than 100 times the PRG. There were some exceedances in the Uplands Area as well.

**Shoreline:** The highest concentration occurred in the northwest corner with a concentration of 6,850 mg/kg collected at A1-04 from a depth of 0.5 feet bgs. A limited interim action and soil removal were conducted in the vicinity of A1-04 during the northwest corner soil removal (Geomatrix, 2007b). The highest copper-affected soils were excavated and disposed of or relocated within the barrier wall area. While the concentrations in the remaining samples that exceed the PRG for copper vary in magnitude, most samples have concentrations less than 100 mg/kg. The PRG exceedances are distributed evenly over the Slip 6 and Duwamish Waterway shoreline soils (Figure 3-11).

**Sediments:** A copper PRG for sediment was not developed; copper is not a Sediment COC listed in EPA's March 17, 2014, PRG memorandum (EPA, 2014).

## Mercury

*Uplands and HCIM:* Mercury concentrations in soil samples in excess of the mercury PRG of 0.048 mg/kg are found primarily in the HCIM Area, grouped in what was termed the "mercury investigation area" during the RFI (CH2M HILL, 1995). The highest concentration was 268 mg/kg in sample A6-03. There were no other mercury exceedances from the HCIM Area at concentrations greater than 20.2 mg/kg. All of the samples with mercury concentrations in excess of the PRG were



collected within 2 feet of the surface, most of them at 0.5 feet bgs. Three soil samples near the southeastern corner of the barrier wall in the Uplands Area exceed 10 times the PRG (Figure 3-12).

**Shoreline:** Mercury concentrations also exceeded the PRG in soil samples collected from the Shoreline Area, with the maximum concentration of 74 mg/kg from a depth of 0.5 to 2 feet bgs in boring SL-08. The remaining sample concentrations in excess of the PRG collected in the Shoreline Area range from 0.05 mg/kg to 2.45 mg/kg. Soil exceedances occur throughout the vadose zone in the Shoreline Area (Figure 3-12).

**Sediments:** A mercury PRG for sediment was not developed; mercury is not a sediment COC listed in EPA's March 17, 2014, PRG memorandum (EPA, 2014).

## Vanadium

**Uplands and HCIM:** There were no exceedances of vanadium in the Uplands or HCIM Areas (Figure 3-13).

**Shoreline:** Vanadium was detected throughout the Shoreline Area at concentrations exceeding the much lower shoreline soil PRG of 1.59 mg/kg in all samples collected during the 2011 shoreline investigation. The vanadium concentrations on the shoreline range from 42.7 to 56.4 mg/kg (Figure 3-13).

**Sediments:** A vanadium PRG for sediment was not developed; vanadium is not a Sediment COC listed in EPA's March 17, 2014 PRG memorandum (EPA, 2014).

#### Zinc

*Uplands and HCIM:* Zinc exceeded the PRG in locations A10A201 and A10A601in the HCIM Area at concentrations of 607 and 691 mg/kg, respectively. There were no exceedances of zinc in the soils collected from the Uplands Area.

**Shoreline:** In the Shoreline Area, zinc was detected at a concentration greater than the shoreline PRG of 86 mg/kg in only one sample, at a concentration of 120 mg/kg from boring SL-13 located on the Slip 6 shoreline at a depth of 0.5 to 2 feet bgs.

**Sediments:** A zinc PRG for sediment was not developed; zinc is not a Sediment COC listed in EPA's March 17, 2014, PRG memorandum (EPA, 2014).



# Minor Inorganic Contaminants

Cobalt and lead were identified as additional metal COCs in the Uplands and HCIM Areas. These metals are not COCs in the Shoreline or Sediment Areas. The cobalt concentrations reported in the RFI do not exceed the PRG based on industrial land use. Lead concentrations in soils exceeded the PRG based on industrial land use in soils collected throughout the HCIM Area, with a few sporadic exceedances in the Uplands Area soils as well. The lead exceedances ranged from 12.5 to 232 mg/kg. With few exceptions, locations with exceedances of lead also exceeded copper PRG levels. Therefore, these locations will be addressed by any recommended corrective measure.

#### 3.2.1.2 Summary of Soil and Sediment COCs by Area

#### **HCIM Area**

The HCIM Area includes the main industrial/chemical storage and manufacturing areas of the site and contains most of the COCs with concentrations above PRGs, including metals (primarily copper but also mercury, lead, and sporadic exceedances of zinc), volatile organic compounds (VOCs) (predominantly toluene but also benzene and ethylbenzene), and semivolatile organic compounds (SVOCs) (pentachlorophenol).

# **Uplands Area**

Toluene is the main COC in the Uplands Area, primarily in the area between the Museum of Flight and the former West Parcel, where high concentrations of toluene were detected during the corrective measures implementation on the East Parcel. There are some scattered metals (copper and mercury) exceedances in the Uplands Area soils as well.

#### Shoreline Area

Soils are impacted with copper throughout the Shoreline Area at depths throughout the vadose zone. Surface soils on the Duwamish shoreline, near the northwest corner of the HCIM, are also impacted with TPH but this contamination does not extend in depth. Mercury also exceeds the PRG in the soils throughout the vadose zone along the Slip 6 shoreline.

#### Sediment Area

Sediments are contaminated primarily with arsenic and PCBs in the upper 10 cm; with only arsenic exceedances at depths of 10 to 45 cm. Benzyl alcohol, the only other COC for sediments, exceeded the PRG at five locations. Benzyl alcohol was found at similar concentrations at an upstream intertidal location very similar to the on-property tideflats suggesting an upstream source.



#### 3.2.2 Contaminants of Concern in Groundwater

COCs for groundwater were determined by EPA for compounds that had been detected in groundwater above the PRGs. The PRGs for potable groundwater and for protection of surface water are applicable to groundwater throughout the four subareas.

# 3.2.2.1 Summary of Groundwater COCs

The groundwater data from the reports listed above (preconstruction and post-construction), the Interim Measures Construction Work Plan (URS, 2002), the RFI (CH2M HILL, 1995), the 1991 Site Assessment (Landau, 1991), and the shoreline and sediment investigations (AMEC 2012a and 2012b), were used to compare the concentrations of COCs identified by EPA to the EPA PRGs. Distribution maps were prepared for contaminants that exceeded PRGs in groundwater samples from more than one sampling location.

Chemical occurrences were mapped as discrete data points rather than using isoconcentration contours. The continuity of concentrations between data points cannot be compared because the highest concentrations in different sampling locations may have been recorded on different sampling dates. Moreover, these maximum observed concentrations do not reflect current site conditions, as the highest concentration samples were collected more than 20 years ago. Therefore, the distribution maps generally reflect the originally investigated nature and extent of contamination at the site, and represent conditions at the time of sample collection only. Significant decreases in contaminant concentrations have likely occurred due to interim measures and degradation processes. Groundwater data from the current monitoring network reflects the highest concentration data collected over the past two years of sampling.

Additional samples were collected in March and June 2014 to provide updated groundwater data for the pilot study work plan and to measure toluene concentrations in groundwater from monitoring wells inside the HCIM that had not been sampled since September 2013, and some not since 2005. Tables summarizing the groundwater chemistry data, the laboratory data reports, and the data review memorandum are provided in Appendix B.

The distribution in groundwater for each compound for which a PRG was developed is discussed below.

# **Organic Compounds**

#### **Toluene**

Toluene has been detected in the groundwater collected from monitoring wells in the HCIM Area at concentrations exceeding the PRG. The highest concentrations are generally found in the southwest



corner of the HCIM inside the barrier wall near the former toluene storage tank location. Toluene concentrations also historically exceeded the PRG in groundwater samples collected from the Shoreline Area in monitoring well DM-8, but toluene has not been detected in the groundwater at concentrations above the PRG at this well, or any of the monitoring wells on the shoreline, since 2002 (Figure 3-14).

Toluene was also detected above PRGs on the eastern site boundary from as a result of a historical release of toluene from process piping that was discovered during demolition activities in 2006. This area has had an on-going interim corrective measure since 2006. Toluene has been variable over the last two years, with some values below the PRG.

# Benzene and Ethylbenzene

Groundwater samples have been analyzed for benzene since 1991 Benzene concentrations have exceeded the PRG of 2.02 micrograms per liter (µg/L) in 14 locations in the Uplands, HCIM, and Shoreline Areas. Most of the locations with exceedances are found in the southwest portion of the site (Figure 3-15) near the former storage tanks. The exact source of the benzene is uncertain; however, its widespread but low-level occurrence suggests it was used as a minor process chemical.

Ethylbenzene has not been detected in groundwater collected from the monitoring wells in the Uplands or HCIM Areas at concentrations exceeding the PRG; nor has ethylbenzene been detected from the groundwater collected from the Shoreline Area at concentrations exceeding the PRG (Figure 3-16).

# Naphthalene and Pentachlorophenol

Naphthalene was detected at a concentration of 2  $\mu$ g/L (above the potable water PRG) in one groundwater sample collected at monitoring well B6, located in the HCIM Area. Groundwater samples have not been analyzed for naphthalene since 2002. Naphthalene was analyzed in the groundwater samples collected during the shoreline investigation, but there were no concentrations greater than the PRG for protection of surface water (Figure 3-17).

Pentachlorophenol also exceeded the PRG in the groundwater from the HCIM Area in monitoring well H-10. Groundwater samples have not been analyzed for pentachlorophenol since 2002.

## **Inorganic Compounds**

The following metals were identified as COCs in the groundwater for the site: aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel, vanadium, and zinc. Copper was used as a catalyst in the production of vanillin. Vanadium is a potential catalyst for production of vanillin and may have been used on-site. Mercury was noted to be associated with the vanillin black liquor solids and



may represent trace contamination concentrated by the manufacturing process. Aluminum, arsenic, cadmium, chromium, lead, nickel, and zinc were not known to be used in the vanillin manufacturing process and may be present due to geochemical factors such as elevated pH or anaerobic conditions. While the elevated pH is not a COC with a PRG, elevated pH increases the solubility and mobility of metals. In addition, the Duwamish Waterway is 303(d) impaired water body for elevated pH.

While the PRGs are either protective of potable groundwater or surface water, the values are the same for groundwater in the Uplands, HCIM, and Shoreline Areas.

#### Aluminum and Lead

Aluminum and lead were detected above their PRGs for protection of surface water primarily in the Shoreline Area, although groundwater from four locations within the HCIM Area and one Uplands Area sample also exceeded the PRG. The groundwater exceedances within the HCIM Area are generally located in the southwest corner of the site. Aluminum is the third most common element in the earth's crust; aluminum solubility is sensitive to changes in pH so it is likely dissolving in the area of elevated pH in the southwest corner of the site, and primarily along the Slip 6 shoreline (Figure 3-18).

Lead concentrations exceeding the PRG are more widespread, with the highest concentrations in the southeast portion of the Slip 6 shoreline (Figure 3-19).

#### Arsenic

Arsenic groundwater concentrations have exceeded the PRG in groundwater in all of the areas of the site with relatively even distribution (Figure 3-20). The occurrence of widespread arsenic in groundwater is due to mobilization under the reducing aquifer conditions. Reducing conditions are known based on the low dissolved oxygen observed in groundwater field parameters measured during quarterly and semiannual monitoring events. Arsenic is not known to have been used at the site, and arsenic concentrations in the soil samples from the site were generally low (Figure 3-20).

#### Copper

Copper concentrations have exceeded the PRG in groundwater in all of the areas of the site, with the highest concentrations inside the barrier wall in the southwest corner and along the Slip 6 shoreline (Figure 3-21).

## Cadmium, Chromium, and Zinc

The PRG exceedances of these metals have primarily been located in the Shoreline Area with sporadic exceedances in the Uplands Area (zinc at monitoring well B1A) and the HCIM Area (chromium at B2, DM-2A, DM-5, and G3, zinc at DM-7, G3, and MW-27) (Figures 3-22 through 3-24).



Each of these contaminants is regularly monitored in groundwater. Though the current reporting limit of 2  $\mu$ g/L for cadmium exceeds the PRG, cadmium has not been detected in groundwater since March 2013, when it was detected in the groundwater at a concentration of 3  $\mu$ g/L in MW-43 (on the Slip 6 shoreline). Chromium and zinc are commonly detected in the groundwater samples; however, in recent years chromium has only exceeded the PRG in groundwater samples from MW-43 and DM-5. Similarly, zinc has been detected in the groundwater from B1A, MW-27, and MW17 recently at concentrations exceeding the PRG. It is likely that the elevated pH in the Slip 6 shoreline has increased the solubility of these metals from naturally occurring minerals.

#### Mercury

Mercury has been detected at concentrations above the PRG in the groundwater in the Uplands, HCIM, and Shoreline Areas (Figure 3-25). The highest concentrations of mercury on site have occurred on the southern boundary of the site near Slip 6. Mercury also was present in the 2011 Shoreline Area groundwater samples.

#### Nickel

Nickel has also been detected at concentrations above the PRG in the groundwater in the Uplands, HCIM, and Shoreline Areas. The highest concentrations have occurred in groundwater samples collected from the Slip 6 shoreline (Figure 3-26). In the HCIM Area, concentrations are highest in the groundwater samples collected from the southwest corner of the site. It is likely that the elevated pH in the southwest corner of the HCIM and the Slip 6 shoreline has increased the solubility of nickel in these areas.

#### Vanadium

Vanadium has been detected at concentrations above the PRG in the groundwater in the Uplands, HCIM, and Shoreline Areas. The highest concentrations in groundwater were recorded in samples collected from the Slip 6 shoreline (Figure 3-27). The highest sample concentration was found in direct push boring location SL-14 at 4,290  $\mu$ g/L (at a depth of 46 to 50 feet bgs). Vanadium may have been used as a catalyst during site operations, and its use as a catalyst may explain why both copper and vanadium concentrations are highest along the Slip 6 shoreline.

#### pН

Elevated pH values ranging from 9.0 to 11.0 occur in groundwater in the southwest portion of the site, inside and outside the barrier wall (Figure 3-28). These elevated levels were caused by releases of caustic solutions that were used in the vanillin manufacturing process. Elevated pH values are limited to the southwest corner and tend to be highest at depths ranging from approximately 35 to 50 feet bgs. Caustic solutions are denser than groundwater, and tend to sink within the aquifer.



# 3.2.2.2 Summary of Groundwater COCs by Area

#### **HCIM Area**

The HCIM Area includes the area where most of the historical industrial/chemical activities occurred, and thus contains the majority of soil and groundwater COC concentrations that exceed PRGs. Specific exceedances include metals (primarily copper but also mercury, zinc, vanadium, and chromium), VOCs (benzene, toluene, ethylbenzene, and xylenes, with toluene predominating), and SVOCs (pentachlorophenol). In addition, soils and groundwater in the southwestern portion of the HCIM Area exhibit high pH due to releases of caustic soda; high pH soils and groundwater extend to the depth of the Intermediate Silt layer at 80 feet bgs. The HCIM Area groundwater is contained by the barrier wall and has been extracted for 12 years to maintain an inward groundwater gradient. During the past 12 years, concentrations of copper and pH have not changed significantly. However, toluene concentrations have declined over the past 12 years in wells being monitored inside the barrier wall near the area of historic toluene releases. This decrease in toluene concentrations is likely due to the operation of the toluene SVE interim measure and the influx of clean groundwater from beneath the aquitard caused by the HCIM groundwater recovery system.

#### **Uplands Area**

The Uplands Area on the eastern and northern sides of the HCIM Area has scattered exceedances of PRGs for VOCs and slight exceedances of the PRGs for aluminum, arsenic, copper, lead, vanadium and zinc. Most of these exceedances are limited to a single well at less than 10 times the PRG.

#### **Shoreline Area**

At the southwest corner of the site and extending eastward along the Slip 6 shoreline, copper, vanadium, and other metals exceed PRGs. The depth of impacts extend to approximately 50 feet bgs, well below the bottom of Slip 6. Copper, zinc, vanadium, mercury, nickel, and lead have been detected above PRGs, although copper predominates, with exceedances in monitoring wells and the 2011 shoreline borings well above PRGs. Dissolved toluene remained above detection limits in samples from groundwater monitoring wells along the shoreline until recently and are now below the toluene PRG.

### 3.3 CONCEPTUAL SITE MODEL

The conceptual site model has been developed to evaluate potential exposure pathways for COCs that exceed PRGs in soil, sediment, and groundwater on the site. The conceptual site model takes into account the different hydrogeologic regimes for the site as a result of the HCIM barrier wall that greatly affects groundwater pathways for the site. Figures 3-29 and 3-30 show the relationships between soil, groundwater, and surface water at the site. The two cross-sections are drawn perpendicular to the Duwamish Waterway and Slip 6 shorelines. These figures summarize the factors



controlling migration of COCs. Based on observed changes in specific conductivity in groundwater samples collected during the shoreline investigation (AMEC, 2012b), the fresh water to saltwater interface (or saltwater wedge) occurs at an elevation of -18 feet below mean sea level in the shoreline. This interface is assumed to connect with the layer of saltwater present in the lower portions of the Duwamish Waterway and Slip 6. Groundwater above this interface will migrate slowly toward the surface water, and groundwater below this interface will stagnate and oscillate in conjunction with the tides and river levels.

Potential exposure pathways that may result in risks to human health and the environment must be addressed by corrective measures considered for the CMS.

# 3.3.1 Potential Exposure Pathways

This section discusses the potential exposure pathways for the CMS under current site conditions.

**Soil:** For soil there are four potential exposure pathways:

- **Soil vapor to air pathway** Inhalation of vapors by industrial workers and/or terrestrial animals resulting from migration of volatile COCs through the soil to ambient air.
- **Soil pathway** Ingestion, dermal contact, or inhalation of particulates by industrial workers and/or terrestrial animals.
- **Soil to surface water and sediments pathway** For those areas without a pavement cap, there is a possibility of contaminated soil eroding into surface water and sediments.
- Sediments pathway Potential for indirect exposure to aquatic birds and aquatic life and
  for dermal contact or ingestion of sediment by fisherman, and human or animal ingestion of
  biota affected by contaminated sediment.

**Groundwater:** For groundwater there are three potential pathways:

- Groundwater to surface water pathway Groundwater to surface water migration of COCs and the subsequent risk to aquatic life and human health via ingestion of fish or other aquatic life. Evaluation of this exposure pathway assumes no dilution (i.e., concentrations of COCs in groundwater are not diluted upon reaching Duwamish surface water).
- **Groundwater to soil vapor pathway**—Industrial workers may be exposed to volatile organics (predominantly toluene) released from groundwater and migrating to ambient air.
- Groundwater to drinking water pathway Groundwater at the site is defined as potable groundwater under the criteria set forth in Washington Administrative Code (WAC) Section 173-340-720(2). Therefore, drinking water is assumed to be the highest beneficial use. Contaminated groundwater used for potable purposes could also result in inhalation via volatilization or mists.



**Sediments:** For sediments there are three potential exposure pathways:

- **Groundwater to surface water pathway** COCs present in groundwater may be adsorbed by sediments, resulting in uptake by aquatic organisms (and potentially by humans via ingestion).
- Sediments to surface water pathway Uptake by biota and incidental human ingestion.
- **Direct contact pathway** Human ingestion and dermal contact with contaminated sediments, such as during clamming.

Previous discussions about potential exposure pathways (CH2M HILL, 1995 and PRC 1990) are no longer applicable to the Site as a whole due to implementation of the HCIM, particularly because the barrier wall substantially altered groundwater flow for the site.

### 3.3.2 Exposure Pathways of Concern

This section discusses the potential exposure pathways for each corrective measures area under current conditions to identify those pathways potentially resulting in risks to human health and/or the environment that must be addressed by the CMS.

# 3.3.2.1 HCIM Area Exposure Pathways

The installation of the barrier wall and groundwater recovery system in the HCIM Area has significantly altered the conditions for this area, affecting mobility and migration of COCs with ramifications for mitigation of site risks. With the barrier wall in place, compounds in soil within the contained area are isolated from the outside environment. Similarly, groundwater within the barrier wall is prevented from migrating to or mixing with the surface water, particularly since the groundwater within the barrier wall flows inward, toward the contained area. As reported by EcoMetrix, since the primary COCs within the HCIM Area are inorganic compounds, particularly copper, the migration of metals through the cement-attapulgite clay barrier wall is not a concern, even without an inward gradient, due to the immense adsorptive capacity of the barrier wall material for metals like copper. A copy of the EcoMetrix report is included in Appendix C.

Figure 3-31 presents the potential exposure pathways applicable for the HCIM Area. The groundwater to surface water and sediments pathway is incomplete for this area because the groundwater is contained by the HCIM and it is not extractable for domestic or industrial use, thereby limiting the potential for direct groundwater exposure for worker other than construction workers. The soil to surface water pathway (as a result of stormwater runoff) is insignificant because the HCIM Area is completely paved and has a stormwater management system that operates under an industrial stormwater permit and routes stormwater to a King County storm sewer, preventing infiltration and leaching. The soil vapor to air pathway that could lead to inhalation of affected particulates is



insignificant due to the extensive paving of the affected area, as is the direct contact (ingestion and dermal contact) with on-site soils pathway; however, construction workers could be exposed to soils during subsurface work. The remaining potential exposure pathway of concern for the HCIM Area is the inhalation of volatile COCs released from soil or groundwater. This inhalation pathway is incomplete at present, as there are not buildings frequented by workers within the HCIM Area. This pathway may be of concern if future development includes building construction.

#### 3.3.2.2 Uplands Area Exposure Pathways

The number, distribution, and extent of COCs in the Uplands Area are much less significant than in the HCIM Area, where the majority of site contaminants are present. Even though the Uplands Area is outside the barrier wall, the soil to surface water and soil to groundwater pathways are insignificant. This is because the entire portion of the Uplands Area affected by soil COCs is paved, and stormwater runoff is managed to prevent contact with soils. For the same reasons discussed above for the HCIM Area, the soil vapor to air pathway is also insignificant for the Uplands Area.

Groundwater flow paths in the Uplands Area were affected by installation of the barrier wall and redevelopment of the site. Groundwater mounds against the upgradient side of the barrier wall and flows north or southeast, around the barrier wall, with eventual discharge to the Duwamish Waterway or Slip 6. Contaminants present in Uplands Area groundwater can flow into surface water and subsequently affect aquatic and/or benthic organisms. Groundwater extracted from this area could be used for domestic and/or industrial use.

Below the water table in the Uplands Area, soil COCs can be released to groundwater, and may subsequently migrate to surface water via the groundwater discharges to the Duwamish River and Slip 6. The soil to surface water and sediments and groundwater to surface water pathways could potentially expose surface water ecological and/or human receptors to some site COCs. During future redevelopment construction in this area, the same potential exposure pathways noted above for the HCIM Area are potentially present in the Uplands Area. The groundwater or soil to air pathways in the Uplands Area are the same as discussed above for the HCIM Area.

#### 3.3.2.3 Shoreline Area Exposure Pathways

Two exposure pathways for the Shoreline Area are complete or potentially complete: (1) soil to surface water and sediments pathway and (2) groundwater to surface water and sediments pathway. Human exposure could result from consumption of biota exposed to affected sediment or affected surface water. Human exposure could also result from direct contact with affected sediment or soil. Most of the Shoreline Area soils are covered with rip rap, minimizing the potential for direct exposure and for erosion.



# 3.3.2.4 Sediment Area Exposure Pathways

The primary pathways of concern for the Sediment Area are exposure of aquatic organisms and/or humans to contaminated sediment and/or porewater. A secondary exposure pathway is humans' exposure via ingestion of fish and/or shellfish.



#### 4.0 CORRECTIVE MEASURES STUDY OBJECTIVES

The primary objective of the CMS is to identify an appropriate and implementable corrective measure that addresses, to the extent practicable, site exposure pathways and associated potential risks, and that reduces potential risks to human health and the environment to acceptable levels. This objective will be accomplished by evaluating a set of corrective measure alternatives designed to achieve an acceptable level of risk reduction. In Section 3, site contaminants were compared to the PRGs established by EPA to establish the nature and extent of contamination to be addressed by the CMS. The hydrogeologic setting was discussed in Section 2.2, and the conceptual site model was outlined in Section 3.3 to describe the exposure pathways and receptors to be addressed by the corrective measures alternatives. Background information and the objectives for the CMS are described below.

#### 4.1 BACKGROUND

The site's four corrective measures areas—the Uplands Area, HCIM Area, Shoreline Area, and Sediment Area—are shown in Figure 1-2 and described below.

- Uplands Area This area includes the uplands portion of the site outside of the barrier wall, to the east and north of the HCIM Area. Groundwater from the Uplands Area flows around the barrier wall—groundwater from the uplands on the east side of the wall discharges to Slip 6 to the south, and groundwater from the uplands north of the wall discharges to the Duwamish Waterway by flowing along the north side of the HCIM Area. Groundwater in this area generally meets PRGs, with the exception of copper, and soil has copper, mercury and lead above PRGs in the shallow subsurface. Potential exposure pathways relevant to the Uplands Area are limited to migration of contaminated groundwater to Slip 6 or the Duwamish Waterway, which could result in contamination of sediment and/or surface water.
- HCIM Area This area is enclosed by the barrier wall. The barrier wall is keyed into the Intermediate Silt and isolates soil and groundwater in the upper aquifer from adjacent areas. Most of the soil and groundwater contained by the barrier wall exceeds PRGs for metals (with copper predominating), VOCs, and SVOCs. Soil and groundwater in the southwest corner of the HCIM Area also exceeds Washington State Department of Ecology water quality standards for pH. Groundwater pH exceeds 8.5 Standard Units down to the Intermediate Silt and has mobilized metals and other constituents present in soil minerals into groundwater within this portion of the shallow aquifer. Potential exposure pathways relevant to the HCIM Area are limited to direct exposure of workers to contaminated soil and/or groundwater via skin contact or ingestion.
- Shoreline Area The Shoreline Area consists of a narrow strip of land between the
  barrier wall surrounding the HCIM Area and surface water within the Duwamish Waterway
  and Slip 6. Soil and groundwater within the Shoreline Area are contaminated with metals,
  PCBs, TPH, and VOCs. An area with high pH is located around the southwest corner of
  the site; the highest pH levels are along the Slip 6 shoreline. Due to the proximity of the
  Shoreline Area to surface waters and sediments, this area has the highest potential for
  migration of COCs and exposure of human and ecological receptors via ingestion and



direct contact. Potential exposure pathways relevant to the Shoreline Area include direct exposure of workers to contaminated soil and/or groundwater via skin contact or ingestion and migration to sediments and/or surface water, resulting in potential exposure of fishermen and aquatic organisms to COCs.

• Sediment Area: The Sediment Area consists of a tideflat located between the Shoreline Area and the Duwamish Waterway. This area has been affected by several COCs that exceed sediment PRGs, including PCBs, arsenic, and benzyl alcohol. The Sediment Area is located within the Lower Duwamish Waterway Superfund site, and must be addressed in accordance with the ongoing CERCLA cleanup action being conducted for the Duwamish Waterway, as discussed in Section 5.3. Potential exposure pathways relevant to the Sediment Area are direct exposure of workers or fishermen to contaminated sediment, surface water, and/or groundwater via skin contact or ingestion. A separate pathway is consumption of biota affected by contaminated groundwater, surface water, or sediment.

Based on the conceptual site model for the four corrective measures areas and the nature of existing site contamination, it is expected that the corrective measures alternatives will include a combination of engineering and institutional controls to achieve the CMS objectives. Additionally, it is expected that the existing barrier wall will be incorporated into most corrective measures alternatives, as it has proven to effectively contain site contaminants over its more than 10-year life.

#### 4.2 OBJECTIVES

Specific corrective measure objectives have been established for the four corrective measures areas described in Section 4.1. These objectives address site COCs and the appropriate exposure pathways identified in the conceptual site model for the corrective measures areas. Remedial objectives for the Sediment Area must be consistent with the cleanup objectives for the Lower Duwamish Waterway Superfund site.

General corrective action objectives have been established for application to the entire site. Specific objectives have been defined for the corrective measures areas that address the specific characteristics and potential exposure pathways of each area.

The following general corrective measure objectives apply to the entire site:

- Protect human health and the environment.
- 2. Attain media cleanup standards.
- 3. Control sources of contaminant releases to reduce or eliminate, to the extent practicable, further releases that may pose a threat to human health and the environment.
- 4. Comply with the applicable regulations and standards for management of wastes.



In addition to the general objectives identified above, the following specific corrective action measure objectives apply to the HCIM, Uplands, and Shoreline Areas:

- 1. Reduce to acceptable levels the short-term and long-term risks to human health and the environment associated with COCs present in the respective areas.
- 2. Control the future release of COCs via groundwater flow, surface water runoff, and vapor migration to meet appropriate media cleanup standards.
- 3. Provide for industrial redevelopment and use of the HCIM and Uplands Areas.
- 4. Incorporate the existing barrier wall into the final site corrective measure to develop a comprehensive approach to implement corrective action for the site.



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#### 5.0 SITE-SPECIFIC CORRECTIVE MEASURES CONSIDERATIONS

The site is located in a heavily industrialized area adjacent to the Duwamish Waterway. General considerations to be addressed by the CMS are described in Sections 1 and 4. Contaminants potentially posing a risk to human health and the environment and PRGs for those contaminants are identified in Section 3. Due to its long history of industrial use, the documented previous cleanup actions, and its location, several site-specific factors must be considered in development of the corrective measures alternatives to be considered in the CMS. The site-specific factors that influence the nature and scope of the corrective measures alternatives to be evaluated for the site are described below.

#### 5.1 LAND USE

The site is located in the city of Tukwila and has a long history of industrial use dating from the 1930s. The site and all adjacent properties, including properties across East Marginal Way South, are located in an area zoned as a Manufacturing Industrial Center/Heavy Industrial (City of Tukwila, Comprehensive Plan & Zoning Map, 2012). As discussed in more detail below, the eastern portion of the site has been redeveloped as the Raisbeck Aviation High School. The Museum of Flight is also located near the site. Figure 5-1 shows the site location, neighboring properties, and the CMS area. The adjacent Duwamish Waterway and Slip 6 are part of an industrial waterway managed by the Port of Seattle. A portion of the site extends into the intertidal area of the Duwamish; this area may be used for harvesting of fish and shellfish. Given the long history of zoned industrial land use for the site, it is expected that land use for the site will remain heavy industrial. The corrective measures alternatives will be designed to support current and future use of the upland portions of the site for industrial purposes. These alternatives also will consider harvesting of aquatic organisms for the portion of the site consisting of sediments within the intertidal area.

### 5.2 Property Ownership Considerations

Previous owners of the site property include I.F. Laucks, Monsanto, Rhone-Poulenc, and Rhodia. Container Properties acquired the site property from Rhodia; this property is generally referred to as the former Rhone-Poulenc site. Laucks, Monsanto, and Rhone-Poulenc operated chemical manufacturing facilities for the production of adhesives and/or vanillin; releases during manufacturing operations resulted in contamination of soil and groundwater. Contaminants have migrated from the property to adjacent properties and toward the Duwamish Waterway and Slip 6.

Current property ownership for the site and neighboring properties is shown on Figure 5-1. The property north of the site is owned by Merrill Creek Holdings LLC., and was previously used by Paccar, Inc. for manufacture of large trucks for many decades. Contamination issues present on the former Paccar property are being addressed under Washington State Department of Ecology



oversight separately from work being done for the former Rhone-Poulenc site. Immediately to the south of the site is Slip 6 and property owned by Boeing; this property also has a lengthy history of industrial activity related to aircraft manufacturing. Boeing owns the entire shoreline of Slip 6, including the northern shoreline located outside the southern fence line of the former Rhone-Poulenc property. In 2006, the former Rhone-Poulenc property was subdivided by Container Properties, LLC, into the East Parcel and the West Parcel to support redevelopment activities; the East Parcel was remediated and subsequently sold to the present owner, the Museum of Flight Foundation. The Museum of Flight property was redeveloped for use as the Raisbeck Aviation High School; portions of the property may be used in the future for museum displays. Container Properties has retained ownership of the West Parcel, which is now leased by International Auto Auctions, Inc. The corrective measures alternatives developed for the CMS must be compatible with the adjacent properties and land uses.

Contaminant releases to the former Rhone-Poulenc site have migrated beyond the current property boundaries. Additionally, the northern shoreline of Slip 6, owned by Boeing, has been affected by site releases and must be addressed by the CMS. These areas are discussed in more detail below.

### 5.2.1 Museum of Flight Property

The East Parcel of the original Rhone-Poulenc property is currently owned by the Museum of Flight Foundation. This property was extensively characterized and remediated, as reported in the East Parcel Soil Characterization and Voluntary Interim Measure Report (Geomatrix, 2006a). The property has been redeveloped with the Highline School District Raisbeck Aviation High School. Construction of the school was completed in 2013 and it opened for the 2013–2014 school year. The voluntary interim measure report notes a small area of groundwater contamination remained in the southwestern portion of the Museum of Flight property. The source of this groundwater contamination was determined to be a toluene release from an underground line located on property currently owned by Container Properties, LLC. EPA issued a Partial Determination of Corrective Action Complete without Controls for the Museum of Flight property, requiring that the area of groundwater contamination near the southwestern corner must be addressed as part of the corrective measures implementation for the remaining portions of the site (EPA, 2006). Cleanup of soils within the Museum of Flight property achieved cleanup levels specified by EPA based on unrestricted land use. The area of contaminated groundwater located on the Museum of Flight property will be addressed in the CMS. The corrective measures considered must be compatible with the current and anticipated future land use for the Museum of Flight property. An access agreement will be obtained as appropriate to implement corrective measures selected for this area.



## 5.2.2 Boeing Property

The southern property line for the site is located approximately along the south fenceline (Figure 5-1). The area immediately south of the south property line consists of the northern shoreline of Slip 6, owned by Boeing. Contaminants released on the former Rhone-Poulenc site have affected soil and groundwater along the north shoreline of Slip 6. An access agreement will be obtained as appropriate to implement corrective measures for this area.

#### 5.3 DUWAMISH WATERWAY

The Duwamish Waterway borders the site to the west of the former Rhone-Poulenc site (Figure 5-1). A portion of the Lower Duwamish Waterway has been designated as a Superfund site by EPA. The NPL site, designated as the Lower Duwamish Waterway Superfund Site, extends approximately 5 miles upstream from Harbor Island, encompassing the portion of the Duwamish Waterway adjacent to the former Rhone-Poulenc site. Cleanup for the Lower Duwamish Waterway Superfund Site is currently being conducted by the Lower Duwamish Waterway Group, which includes four potentially responsible parties: King County, Boeing, the City of Seattle, and the Port of Seattle. An additional 111 parties have been notified that they are potentially responsible parties for the Superfund site, including Container Properties (the current site owner), Bayer CropScience, and Monsanto.

The CMS will address site contamination within the Sediment Area, which lies between the Duwamish Waterway and the Shoreline Area inside the Container Properties property line. Contamination within the tideflat and other portions of the Duwamish Waterway outside the former Rhone Poulenc site property line will be addressed under the CERCLA cleanup process for the Lower Duwamish Waterway Superfund site. Remediation of the sediments located on the former Rhone Poulenc site owned by Container Properties will be addressed in the CMS. Sediment cleanup is subject to the cleanup requirements for the Superfund site. The Proposed Plan, Lower Duwamish Waterway Superfund Site (Proposed Plan) was issued by EPA in February 2013 (EPA, 2013). This plan establishes a framework for designing and implementing cleanup actions within the Lower Duwamish Waterway Superfund site and designates portions of the tideflat located on the former Rhone Poulenc site for cleanup action. The cleanup action alternatives developed to address the sediments on the former Rhone Poulenc site will be designed to be consistent with remedies specified in the Proposed Plan, and will address the recovery categories, technologies and remedy implementation flowcharts specified in the Proposed Plan.

As noted in the Proposed Plan, the Duwamish Waterway has been designated as critical habitat for Chinook salmon and bull trout, which have been listed as threatened species under the Endangered Species Act. CMS alternatives developed for sediments must consider potential effects on critical habitat for these species. Additionally, corrective measures alternatives for the HCIM and Uplands Areas must be designed and implemented with minimal impact on these species.



## 5.4 EXISTING SITE INTERIM MEASURE

As noted previously, Container Properties implemented the HCIM in 2003 to establish hydraulic containment of the most highly contaminated portion of the site. The HCIM has proven to be effective in establishing hydraulic control and in limiting the migration of site contaminants. In addition to controlling the migration of contaminated groundwater, the HCIM has also induced changes to site groundwater in areas downgradient of the barrier wall. The physical components of the HCIM and the induced changes to groundwater must be considered in development of corrective measures alternatives for the site. These considerations are discussed below.

#### 5.4.1 HCIM Area

The HCIM Area (Figure 1-2) is the area enclosed by the barrier wall that was constructed in 2003 and where groundwater recovery commenced full operation in 2004. The HCIM consists of a low-permeability barrier wall completely enclosing the HCIM Area, a groundwater recovery well system, a pretreatment system, and a network of piezometers used to monitor hydraulic control performance. The barrier wall is keyed into an aquitard that lies beneath the shallow aquifer present at a depth of about 80–90 feet bgs. The aquitard is believed to be continuous within the HCIM Area, based on site characterization, design, construction, and monitoring data. The interim measure has proven effective in establishing and maintaining hydraulic control of contaminated groundwater enclosed by the barrier wall. The interim measure has essentially isolated shallow groundwater within the HCIM Area from the shallow groundwater aquifer outside the barrier wall. Additionally, the interim measure has prevented migration of contaminated groundwater toward the Duwamish Waterway and Slip 6, resulting in improved groundwater quality in the shallow aquifer outside the barrier wall. The interim measure also represents a significant monetary investment for site remediation that has provided substantial environmental benefits.

Due to its proven effectiveness and potential to provide long-term environmental benefits, the HCIM will be incorporated into most of the corrective measures alternatives for the HCIM Area. Remediation alternatives for the other remediation areas located outside the HCIM Area will be designed to be compatible with the existing HCIM, as appropriate.

## 5.4.2 Shoreline Area Groundwater Hydrology and Geochemistry

Groundwater within the Shoreline Area has a unique geochemical and hydrological environment that has been created by a combination of the surface water within the Duwamish Waterway and Slip 6, the barrier wall enclosing the HCIM Area, and caustic soda releases that have affected groundwater within the Shoreline Area. The barrier wall, which was constructed in 2003, has substantially altered the flow of groundwater within of the Shoreline Area. The changed hydrologic conditions have in turn contributed to changed geochemical conditions in the groundwater. The geohydrological and



geochemical conditions present in Shoreline Area groundwater must be considered in the design and evaluation of cleanup measures for this portion of the site.

#### 5.4.2.1 Groundwater Hydrology

The hydrology of groundwater within the Shoreline Area is influenced by the presence of the barrier wall and saltwater within the adjacent Duwamish Waterway and Slip 6. The low-permeability barrier wall around the HCIM Area was completed in 2003; this wall is keyed into an aquitard that is present approximately 80–90 feet bgs. Prior to construction of the barrier wall, fresh groundwater above the aquitard flowed from the HCIM Area through the Shoreline Area to either the Duwamish Waterway or Slip 6. The barrier wall has substantially decreased the flow of groundwater through the Shoreline Area, resulting in a significantly increased residence time for groundwater within the Shoreline Area and in reduced flux of groundwater from the Shoreline Area to the Duwamish Waterway and Slip 6. As discussed in Section 3.3, only the upper portion of the Shoreline Area that is subject to infiltration of precipitation has significant groundwater flow. The groundwater zone beneath the region subject to surface water infiltration is expected to be essentially stagnant, with no significant groundwater movement.

The "saltwater wedge" present within the Shoreline Area is created by density gradients between the saltwater and freshwater that are present in the Duwamish Waterway and Slip 6 (Section 3.3). The reduction in freshwater flow into the Shoreline Area caused by the barrier wall has likely increased the elevation of the saltwater zone. The elevation of saltwater within the saltwater wedge within the Shoreline Area is controlled by the elevation of saltwater in the Duwamish Waterway and Slip 6; changes in elevation will be caused primarily by changes in the head on saltwater in the surface water bodies. Shoreline Area groundwater within the saltwater zone is essentially stagnant, with minimal movement toward the Duwamish Waterway and/or Slip 6.

The existing hydrologic conditions within the Shoreline Area limit the potential for migration of contaminated groundwater into surface water. Under current groundwater hydrological conditions within the Shoreline Area, long restoration times can be accommodated to attain cleanup objectives. Under existing hydrological conditions, corrective measures that rely on injection of chemicals into the Shoreline Area would cause an approximately equal volume of Shoreline Area groundwater to flow into the adjacent surface water.

#### 5.4.2.2 Groundwater Geochemistry

The barrier wall created hydrological conditions within Shoreline Area groundwater that have contributed to a change in groundwater chemistry within the freshwater zone. Groundwater geochemistry is affected by interaction of the groundwater with the soil matrix present in the saturated zone. Prior to construction of the barrier wall, groundwater from the HCIM Area would flow through the



Shoreline Area prior to discharging into the adjacent surface water. This flow resulted in approximately steady state conditions, which are established by chemical interactions between soil and groundwater, including dissolution/precipitation reactions and adsorption reactions. Steady state conditions are established by the relative rates of the solid-liquid reactions and the groundwater flow. The generally stagnant conditions created by the barrier wall increased the contact time between Shoreline Area groundwater and saturated soils, allowing the solid-liquid reactions to approach equilibrium conditions due to a much longer contact time. A significant chemical interaction between the high pH groundwater and soils present in the Shoreline Area has resulted in the dissolution of silica (likely quartz) that is typically present in sand. As the pH of water increases above 10, silica solubility increases due to ionization of silicic acid. High pH in the Shoreline Area must be addressed in the CMS to create conditions conducive to *in situ* stabilization of metals (such as copper) that tend to be co-located with the high pH groundwater.

Evidence of the change in groundwater chemistry is found in the groundwater monitoring data collected after the barrier wall was completed early in 2003. Figure 5-2 shows measured concentrations of total silicon (as silica) versus pH from the fall of 2003 through the end of 2005 for three monitoring wells with high pH values (MW-41, MW-43, and MW-44). These data show a slight increase in silica level for MW-41 (pH around 10, which is the consistent with the first dissociation point for silicic acid) while silica levels increased substantially in MW-43 (pH ranging from approximately 9.1 to a pH of 10.5—a level above the first ionization point) and MW-44 (pH ranging from approximately 10.2 to 11.0, well above the first ionization point). Figure 5-2 shows a substantial increase in total silica for groundwater in these wells as the pH increased. Figure 5-3 shows a pH and silicon trend plot for well MW-44, the well with the highest pH recorded during the 2003 to 2005 monitoring period. Results from Figures 5-2 and 5-3 suggest that a steady-state condition existed prior to barrier wall construction (i.e., during the time groundwater flowed from the Site to the Shoreline Area), and that conditions changed to a new steady-state condition after the barrier wall intercepted groundwater flow from HCIM Area.

An equilibrium simulation model was created using Visual MINTEQ, a free, downloadable, widely used aqueous equilibrium model. The model was run using groundwater analytical data for MW-44 from the June 2005 Round 28 sampling results (Round 28 data point is shown on Figure 5-3). Results from the equilibrium model are plotted in Figure 5-4 for comparison with the measured total dissolved silica for the high pH wells previously plotted on Figure 5-2. The equilibrium calculations show good agreement with measured total silica results for pH values up to approximately 10.8, indicating that the Shoreline Area groundwater is essentially in equilibrium with amorphous silica. Measured results for pH values greater than approximately 10.8 are below equilibrium levels, indicating that the very high pH groundwater is not in equilibrium, that the chemistry input to the MINTEQ model is incomplete, or measurements (such as pH) may not be accurate.



The measured total silica data presented in Figure 5-4 also show the potential for generation of suspended solids when high pH groundwater is neutralized. The data show that lowering the pH of Shoreline Area groundwater from 10.5–11 to below 9.0 would cause total silica concentrations to decrease from about 1,300 milligrams per liter (mg/L) to about 125 mg/L. Precipitation of such a large quantity of solids could have significant effects on injection equipment (e.g., wells, push probes) and on the soil matrix. The potential for precipitation of solids must be considered when developing and evaluating potential corrective measures.



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#### 6.0 CORRECTIVE MEASURES TECHNOLOGIES

In order to identify comprehensive corrective measure alternatives, remediation technologies that may be effective and appropriate for each of the four corrective measures areas must be identified. These potentially applicable technologies can then be combined to develop corrective measures alternatives for each corrective measures area that attain objectives across the entire site while maintaining existing site objectives (i.e., maintaining the integrity of the existing HCIM). The Sediment Area is located within the Duwamish Waterway Superfund site and is, therefore, subject to cleanup requirements specified under the CERCLA cleanup program. A feasibility study has been completed for the Duwamish Waterway Superfund site, and cleanup actions have been specified for the Sediment Area to be addressed by the CMS. Therefore, the technologies in the feasibility study will primarily be used in the alternative development. There is no need to screen technologies for sediment remediation, as this was done in the Proposed Plan.

The remedial technologies for soil and groundwater that are feasible for the site are identified using a two-step screening process, consistent with EPA RCRA Corrective Action Plan guidance (EPA, 1994). The first step, as outlined in this section, was to identify potentially applicable remedial technologies appropriate for site COCs that have been proven in full-scale applications or that have been used in pilot-scale programs and appear to be potentially feasible for use at the site. The potentially applicable remedial technologies are subsequently screened using appropriate criteria to prepare a "short list" of potentially applicable remedial technologies, which are then used to develop appropriate corrective measures alternatives for each target area (see Section 7).

#### 6.1 Preliminary Screening of Sediment Remedial Technologies

The Lower Duwamish Waterway Group looked at technologies to address areas of potential concern in the Sediment Area in their Focused Feasibility Study for the Lower Duwamish Waterway (AECOM, 2012). In the Focused Feasibility Study, several technologies were evaluated based on three primary categories: sediment removal, physical containment, and natural recovery. Sediment removal consists of physical removal by dredging with treatment of the sediments and/or on-site/off-site disposal. Physical containment or the isolation/reactive capping of the contaminated sediments considered using engineered layers of sand, gravel, or rock. Natural recovery may be passive or active. The passive approach looked at using monitored natural recovery to reduce surface sediment concentrations through natural burial of the contaminated sediments with clean sediments (e.g., net sedimentation areas). A more active approach to natural recovery looked at ENR, which includes placement of a thin layer of materials, such as sand, to enhance the recovery process, or addition of amendments, such as activated carbon, to the thin layer to reduce the bioavailability and toxicity of contaminants. All sediment technologies discussed above were retained for consideration in the final alternative evaluation for the Sediment Area (Table 6-1).



## 6.2 Preliminary Screening of Soil Remedial Technologies

As part of the preliminary screening process, potentially applicable remedial technologies were identified based on professional experience, professional literature, and other technical resources, including the Federal Remediation Technologies Roundtable and Contaminated Site Clean-Up Information website. Only remedial technologies applicable to the site COCs identified in Section 3.2 of this report were considered for screening. In general, unproven technologies that had only been evaluated in laboratory or pilot scale studies were not considered potentially applicable to the corrective measures areas. Technologies proven in field applications or where pilot testing indicated a high potential of successful application were included for further consideration.

Soil remediation technologies have been separated into three main categories: *in situ* treatment, *ex situ* treatment, and containment. In addition, removal and off-site disposal may be needed. The soil remediation technologies considered potentially applicable for the site are listed in Table 6-2 with screening details included in Table 6-3. Table 6-2 also describes the site soil contaminants addressed by each technology; for example VOCs and SVOCs. The soil remediation technologies retained after preliminary screening for soil and groundwater technologies are listed in Table 6-1.

## 6.2.1 In Situ Soil Remediation Technologies

*In situ* soil remediation technologies have been developed for the remediation of contaminated soil in place. These technologies use natural, biological, chemical, or physical processes that transform, destroy, separate, or immobilize soil contaminants. In general, *in situ* technologies require minimal site disturbance for implementation. Some technologies are passive while others are more active, requiring significant activity to implement. The *in situ* soil remediation technologies are discussed in the following subsections.

#### 6.2.1.1 Enhanced Bioremediation

Enhanced bioremediation approaches involve the addition of substrate to the vadose zone through direct injections (oxygen releasing compounds [ORC®] or substrate). The addition of ORC® into the soil may promote aerobic biodegradation of the soil constituents. Substrate may be added to assist in aerobic biodegradation or to assist in anaerobic biodegradation. This approach would potentially address the VOCs at the site, but would not likely address SVOCs. Most metals are unaffected by the introduction of oxygen to create aerobic conditions or substrate to promote anaerobic degradation.

Enhanced bioremediation is a proven technology that performs well in permeable soils with aerobically degradable contaminants or potentially anaerobically degradable contaminants. Due to the potentially limited radius of influence for injection and/or extraction wells and the fairly large areas requiring remediation at the site, a large number of wells may be required to implement this



technology at the site. To get a distribution across vadose zone soils, mixing of the substrate would likely be required. Additionally, residual mineral oil with dissolved toluene in the vadose zone soil near the water table would not degrade readily, because substrate diffusion through water or hydrocarbon filled pores would be much slower than in the bulk of the vadose zone. Based on the history of this use and our understanding of the site, enhanced bioremediation of the vadose zone alone will be inadequate to attain cleanup levels. This technology also would have no effect on groundwater constituents. Based on these issues, this technology was rejected from further consideration.

### 6.2.1.2 Phytoremediation

This approach to soil remediation involves planting contaminant- and climate-tolerant plants in the soil to selectively remove contaminants, and/or to provide a means of biodegradation of organics. Phytoremediation may remediate COCs through several treatment processes, including storing the contaminants in the roots, stems, or leaves of the plant; converting the contaminants into less harmful chemicals (typically in the root zone of the plant); converting the contaminants into vapors that are released to the air; or through sorption onto the plant's roots. Phytoremediation can be effective for some metals and organics (including TPH and toluene). In general, phytoremediation is only effective to the depth of root penetration.

Phytoremediation at the site would require establishing plants that can both survive in the local climate and that have been shown to effectively remediate COCs observed at the site. The plants used at the site must to be able to tolerate the concentrations of the contaminants at the site. Given the depth of soil contamination at some site locations, the plant's root zone would be insufficient. In addition, plants would need to be densely planted to treat site contaminants and would likely disrupt productive use of the site. During growth periods, plants would require regular maintenance, such as watering or fertilization. Phytoremediation could also take a very long time to remediate the COCs present at the site. Given the numerous uncertainties present with this technology for the site that may affect success, the disruption of site activities, and the proximity of the site to marine waters in the Duwamish Waterway; this technology was rejected from further consideration.

#### 6.2.1.3 Soil Vapor Extraction

SVE is a well-established technology, applicable primarily to VOCs in the vadose zone. SVE involves the extraction of soil vapors from wells distributed in the vadose zone and operated under a moderate vacuum. Contaminants in the soil are volatilized and removed with the extracted soil gas, which is either discharged to the atmosphere or treated to separate or destroy contaminants. This technology also results in the introduction of oxygen to the vadose zone by creating a vadose zone air current, which can contribute to aerobic biodegradation of the organic COCs if conditions are appropriate. SVE is applicable to VOCs and would target toluene and the more volatile TPH components present at the site. Metals and low-vapor pressure organics would not be effectively removed by SVE.



SVE was used within the HCIM Area for several years as part of an earlier interim action prior to installation of the barrier wall, recovering several thousand pounds of toluene. A small SVE system was also used in conjunction with an air sparging system to remove toluene from the vadose zone soils and groundwater within the Uplands Area. The SVE systems have been shut down and removed from the site, as recoverable toluene within the vadose zone has been effectively removed. Based on the prior application of SVE at the site, minimal potential for continued effectiveness in removing organic constituents is expected. For this reason, this technology was rejected from further consideration.

#### 6.2.1.4 Bioventing

Bioventing involves the addition of oxygen to the vadose zone through extraction of soil vapors under low vacuums to induce oxygen flow into the subsurface or through the injection of oxygen/air into the vadose zone. The addition/displacement of oxygen/air in the vadose zone supports aerobic biodegradation of organic constituents and may release adsorbed phase constituents from the soil into the vapor phase that may then be collected and treated through an SVE system. Most metals are unaffected by the introduction of oxygen to create aerobic conditions.

Bioventing performs well in permeable soils with aerobically degradable contaminants and is a proven technology. Due to the potentially limited radius of influence for injection and/or extraction wells and the fairly large areas requiring remediation at the site, a large number of wells may be required to implement this technology at the site. Additionally, residual mineral oil with dissolved toluene and/or methylene chloride in the vadose zone soil near the water table would not degrade readily, because oxygen diffusion through water or hydrocarbon filled pores would be much slower than in the bulk of the vadose zone. A combination of air sparging and an SVE system has been used in the upland toluene source area (east of the barrier wall) to reduce volatile toluene levels in both the soil and groundwater. Based on the history of this use and our understanding of the site, bioventing in the vadose zone alone will be inadequate to attain cleanup levels. This technology also would have no effect on groundwater constituents. Based on these issues, this technology was rejected from further consideration.

#### 6.2.1.5 Soil Flushing Using Co-Solvents or Chelating Agents

This approach to soil remediation involves injection of co-solvents or surfactants into the soil to mobilize contaminants, which in turn are recovered from the saturated zone. Co-solvents have been used for recovery of organic constituents from soil, specifically for fuels and chlorinated solvents. Co-solvents incorporating chelating agents can be effective for removal of soluble metals. Different co-solvents/chelating agents would be required for organics and metals. Co-solvent/chelating flushing can, however, spread contaminants if applied without effective containment. Additionally, complete recovery of co-solvents/chelating agent solutions from the saturated zone can be difficult to achieve.



Site soil constituents that could be addressed with this method include toluene, TPH, SVOCs, and metals. Co-solvent flushing of metals has not been established as a proven technology.

Handling of co-solvents and injection into areas outside the HCIM Area could cause releases to the adjacent Duwamish Waterway and/or Slip 6, potentially creating adverse environmental impacts. Preferential flow pathways may limit uniform distribution of co-solvent and solvent recovery, and subsequent attainment of cleanup standards. This technology has mainly been proven in full-scale petroleum hydrocarbon recovery applications with limited solvent recovery applications and very little metal recovery application. As such, numerous uncertainties are present with this technology that may affect success. Based on these issues and the proximity of the site to the Duwamish Waterway, this technology was rejected from further consideration.

#### 6.2.1.6 Thermal Remediation

Thermal remediation consists of three technologies that rely on the same principals to remediate soil, and involves heating the subsurface to promote volatilization of organic COCs. Electrical resistance heating is conducted by inserting electrodes into the ground and applying a strong electrical current, causing the soil to become heated through the resistance to current flow in the soil. Radio frequency heating uses the application of high frequency electromagnetic energy to the soil through a series of electrodes, causing moist soils to heat up and release VOCs into the soil gas phase. Steam injection involves injecting steam into the soil through a series of wells that effectively heat the soil and volatilizes organics into the soil gas phase. The heated VOCs that are released from the soil into the soil gas are then typically collected using SVE techniques. The organic vapors are usually separated from soil gas (via adsorption onto carbon or condensation) or destroyed using thermal oxidation. Thermal remediation technologies can perform well in permeable soils with VOCs. For the former Rhone-Poulenc site, this approach would target benzene, toluene, ethyl benzene, TPH, naphthalene, and some SVOCs; metals would not be affected by this remedial technology.

Underground utilities (lines, sewers, power lines) or other subsurface structures (e.g., buried trees as encountered during the burial wall construction) could disrupt power distribution and result in incomplete remediation. Some surface and subsurface demolition within affected areas would be required for this technology to affectively remediate the site. Very large energy requirements would be required to operate this technology, and the technology could be required for an extended period of time to accomplish affective remediation, given the unknown subsurface effects on the distribution of the heat. Excessive temperatures may be required for mineral oil, and the technology would not be effective for removal of the mineral oil. Residual mineral oil could contain dissolved toluene, potentially leaving a residual source after heating has been completed. The heating of groundwater could result in transport of hot groundwater into the nearby Duwamish Waterway, resulting in adverse ecological



impacts on the waterway. Based on these concerns, the thermal remediation technologies were rejected from further consideration.

# 6.2.2 Ex Situ Soil Remediation Technologies

Ex situ remediation technologies require that affected soils be excavated and treated on the surface. Because ex situ technologies are not subject to the constraints imposed on in situ remediation methods, a greater variety of treatment methods are available. While ex situ treatment can be performed either on or off site, only on-site methods have been considered potentially applicable to the former Rhone-Poulenc site, due to the large volume of affected soil and the absence of nearby commercial hazardous waste treatment facilities. The nearest commercial hazardous waste treatment facilities are located more than 250 miles away. Significant risks to human health and the environment could result from transportation of excavated material from the site to remote treatment facilities. The detailed screening of ex situ soil remediation technologies potentially applicable to the site is presented in Table 6-2 and discussed in more detail below. Table 6-3 summarizes the preliminary screening for the ex situ treatment technologies considered applicable for the site.

## 6.2.2.1 Biopiles and Landfarming

In Biopile or landfarm treatment, excavated soil is piled or spread on the ground, mixed with appropriate amendments, and irrigated with nutrient-containing water to encourage biodegradation of organic contaminants. Aeration may be accomplished by periodic tilling (landfarming) or by placement of piping to allow air to flow into the biopile. Amendments can include biological seed and nutrients such as animal manure, pH modifiers, chemical fertilizer, commercially available bacterial cultures, or bulking materials such as sawdust or straw. Biopiles and landfarms are usually placed over protective liners and a collection system to collect the leachate and to prevent infiltration to groundwater. Metals (such as copper) are generally unaffected by biodegradation and may inhibit biodegradation if present in soil at toxic levels. TPH, naphthalene, and low molecular weight VOCs would be the targeted COCs for this treatment method. Heavier organics would not likely be effectively removed. Biopiles and landfarms can perform well with biodegradable and non-volatile organic compounds. VOCs present in excavated soils may be lost to the atmosphere from the biopiles.

Extensive surface and subsurface demolition would be required for these technologies, which would interrupt site operations. Biopiles and landfarms would require significant acreage for several months or more for degradation of TPH and toluene. Excess precipitation over the biopiles and landfarms can cause erosion if the slopes are not properly stabilized and protected; runoff protection is needed for controlling stormwater quality. Some locations at the site have high pH groundwater (over 10 Standard Units), which would require pH amendment to avoid inhibiting biodegradation of the COCs. Excavation also could encounter natural obstructions (such as buried trees or other buried objects) and would require shoreline permitting due to the site's proximity to the Duwamish Waterway. The



magnitude of required excavation and the presence of contaminated soil adjacent to the barrier wall could adversely impact the integrity of the barrier wall. Significant water management issues would be caused by the accumulation of water in the excavation during treatment and by the need to control stormwater runoff. In addition, a water treatment system would likely be required to collect and treat leachate from the biopiles or landfarms with any impacted runoff. TPH, toluene, benzene, and ethyl benzene would volatilize during excavation and treatment, which could present a worker health risk. For these reasons, these technologies were rejected from further consideration.

#### 6.2.2.2 Solidification/Stabilization

Ex situ stabilization is similar to *in situ* solidification/stabilization, as described above, except that treatment is performed after contaminated soil has been excavated. Treatment amendments and chemicals are the same as discussed for *in situ* treatment and the technology addresses the same site contaminants. Excavated soil is mechanically mixed with the amendments using conventional methods, such as a pug mill. Large objects, such as buried trees, would be either removed from the site or ground up to yield an appropriate particle size. Treated soil is typically stockpiled to cure and then either placed back into the excavation or transported to an off-site disposal facility. As noted for *in situ* stabilization, approximately 20–25 percent of the excavated soil volume would require off-site disposal due to the volume increase created by addition of the amendments. This technology would be effective primarily for metals.

Solidification and/or stabilization of the excavated soils would be done by excavating contaminated soils to the appropriate depth. Surface and subsurface improvements would have to be demolished in order to complete the excavation. The large volume of affected site soil would require an extensive quantity of fixation chemicals. Soil cleanup levels would not be met with this technology because metals would remain in the excavated soils. Buried trees, which were encountered during installation of the barrier wall, would complicate implementation of this technology. The magnitude of required excavation and locations of contamination adjacent to the barrier wall could have adverse impacts on the integrity of the barrier wall. A large land area would be required for curing the treated soil; this would not be available due to the large excavation area. Significant water management issues would be caused by the accumulation of water in the excavation during treatment and by the need to control stormwater runoff. TPH, toluene, benzene, and ethyl benzene would likely volatilize during excavation and treatment, potentially creating a worker health risk. Based on these issues, the technology was rejected for further consideration.

#### 6.2.2.3 Thermal Desorption

Thermal desorption for *ex -situ* soils is accomplished by feeding excavated soil to a fired kiln that heats the soil to an appropriate temperature to desorb the target organics. Off gas from the thermal desorber is typically fed to a collection and treatment system that typically incinerates desorbed



organics. Energy for heating is supplied from fuel (e.g., natural gas) or electricity to maintain treatment temperatures near 1,000 degrees Fahrenheit. Treated soil is stockpiled for characterization prior to placement in the excavation.

Since this technology requires excavation, the same issues regarding site use, the impacts of site improvements, and other excavation issues noted above apply equally to this technology. Substantial fuel or electrical energy is needed to effectively volatilize the target COCs, which would create a significant carbon footprint. For these reasons, thermal desorption was rejected from further consideration.

## 6.2.3 Physical Containment/Removal Technologies

Containment/removal technologies are used to either physically contain and isolate contaminated areas from the environment or to remove the contamination and isolate contaminated soil in an off-site engineered landfill. Containment and removal technologies are used frequently to significantly reduce the migration of contaminants in soils. Containment technologies include capping of the soils in place with a low-permeability engineered cap to prevent infiltration of stormwater and placement of a low-permeability barrier wall to limit potential transport of COCs from the contaminated soil. Physical removal technologies typically require excavation of affected soils with off-site transport for landfill disposal.

### 6.2.3.1 Capping

Capping involves placing a low-permeability engineered cap over the affected soils to minimize infiltration and the potential for generating contaminated groundwater that may migrate downgradient. Capping is applicable to all contaminant types. Capping does not destroy or reduce overall contaminant mass, but it limits one potential pathway for contaminant migration. Capping has a well-established performance record, and is proven effective for limiting influx of surface water and preventing erosion of contained material. Capping is usually implemented in conjunction with other remediation technologies. Caps are typically designed to promote stormwater runoff and resist erosion. Regular inspection and maintenance is needed to maintain cap effectiveness.

An asphalt cover is present over the entire HCIM Area and the Uplands Area at the site; this cover supports the present use and is projected to support future industrial site use. Capping may not be compatible with the Shoreline Area. Given these benefits and the relative ease of implementation, capping has been retained as a technology for further consideration.

#### 6.2.3.2 Solidification/Stabilization

*In situ* stabilization involves injecting additives and/or amendments, thus promoting chemical reactions and conditions that chemically immobilize COCs or reduce the solubility of the COCs. *In situ* 



solidification involves encapsulating COCs in the soil by decreasing the exposed surface area of the contaminated soil, thereby limiting the potential for COC leaching. Chemical reactions may result from addition of solidifying reagents such as Portland cement, cement kiln dust, or fly ash, all of which may be injected or mechanically mixed into the soil. The encapsulation or immobilization technologies have been primarily effective for metals; these methods have not been highly successful with low molecular weight organic contaminants. In order for the technology to be effective, the pozzolans added must be uniformly and completely distributed throughout the affected soil matrix. Stabilized metals in the subsurface can be effectively immobilized with a very long effective life; however, this technology does not remove/degrade contaminants from the soil matrix. Stabilized metals also can be released if the soil becomes acidic in the future.

The volume of affected soil at the site would require an extensive distribution of fixation chemicals to effectively immobilize COCs in site soil. For *in situ* soil mixing, this would require demolition of all surface and subsurface structures within the affected areas. The addition of cement or other stabilization additives may also cause a 20 to 25 percent soil volume increase, resulting in substantial changes in site topography or in substantial removal of excess materials to an off-site landfill. This technology would not meet soil cleanup levels because metals would remain in site soils and be subject to erosion. Buried trees, which were noted during installation of the barrier wall, would also complicate implementation of this technology. Although difficult and expensive to implement, *in situ* soil stabilization could be effective in immobilizing metals and could decrease soil permeability to decrease the potential loss of organic COCs. For these reasons, this technology has been retained for further consideration.

#### 6.2.3.3 Off-Site Landfill Disposal

For off-site disposal, contaminated soils would be excavated and transported off-site for disposal at an approved disposal facility. This technology has a well-established performance record that would address nearly all of the site contaminants, including toluene, benzene, ethyl benzene, TPH, PCBs, and metals. Excavated soils must be characterized in accordance with Dangerous Waste regulations. It is expected that much of the excavated soil contaminated with toluene would be a RCRA hazardous waste, requiring treatment prior to disposal at a Subtitle C landfill. Treatment would likely require incineration, resulting in a substantial carbon footprint.

During soil excavation at the site, VOCs may volatilize into the air space, potentially creating a worker and environmental hazard. Engineering controls may be required to limit excessive air releases of volatile COCs. In addition, any on-site removal, storage, and transport of the excavation spoils create potential risk for contaminant releases to the Duwamish Waterway. To effectively remediate the site, extensive surface and subsurface demolition would be required to implement large scale excavation needed to achieve cleanup. Excavation would require shoreline permitting due to the proximity of the



waterway, and any dewatering water would require permitting. The proximity of contamination to the barrier wall could adversely affect the barrier wall integrity. Given that this technology may be used as a hot spot treatment for the Shoreline and Uplands Areas, this technology will be retained for consideration.

## 6.3 GROUNDWATER REMEDIATION TECHNOLOGIES SCREENING

Potentially applicable remedial technologies for groundwater were identified based on professional experience, professional literature, and other technical resources such as the Federal Remediation Technologies Roundtable and Contaminated Site Clean-Up Information website. Only remedial technologies applicable to the groundwater COCs identified in Section 3.3 were considered for screening. In general, unproven technologies that had only been evaluated in laboratory or pilot scale studies were not considered potentially applicable to the site. Technologies proven in field applications or where pilot testing indicated a high potential of successful application were included for further consideration.

Groundwater remediation technologies have been split into three main categories for screening: *in situ* treatment technologies, *ex situ* treatment technologies, and physical containment or disposal technologies. Brief descriptions of the technologies potentially applicable for groundwater remediation are described below and summarized in Table 6-4, which also describes the site contaminants addressed by each technology for groundwater; such as VOCs and SVOCs. Technology screening is summarized in Table 6-5. The groundwater remediation technologies retained after preliminary screening for soil and groundwater technologies are listed in Table 6-1.

### 6.3.1 In Situ Groundwater Remediation Technologies

*In situ* groundwater remediation technologies have been developed to remediate groundwater in the subsurface and do not require groundwater extraction. These technologies can use natural processes, biological processes, and/or chemical processes that destroy or immobilize groundwater contaminants. The technologies can be passive, requiring minimal operation to implement, or active, requiring significant operations.

#### 6.3.1.1 Monitored Natural Attenuation

Monitored natural attenuation (MNA) relies on natural processes to attenuate contaminants in groundwater. Attenuation can occur through multiple processes, including natural biological degradation, sorption onto soils and organic carbon in the aquifer matrix, dilution/dispersion of the contaminated water with clean water flowing through the site, and naturally-occurring abiotic degradation mechanisms. In MNA, these natural processes are monitored by sampling and analyzing groundwater samples to assess trends in COC concentrations and other indicator parameters that



characterize the geochemical environment in the aquifer (such as dissolved oxygen for aerobic degradation and ethenes/ethanes for anaerobic reductive dechlorination). Under proper conditions, MNA can naturally reduce levels of contaminants to achieve cleanup criteria. Dissolved metals will not be removed but may become immobile through naturally-occurring chemical reactions or sorption onto the aquifer matrix.

MNA is applicable to all contaminants present on site, and could be readily used in combination with other technologies. However, MNA may not achieve cleanup criteria for the metals present in groundwater and would likely take a long time to clean up the VOCs and SVOCs, thus requiring long term containment of groundwater. The construction of the barrier wall has significantly reduced groundwater flow from the most highly contaminated portions of the site; the barrier wall has been proven effective and has significantly slowed groundwater flow to the Shoreline Area, thereby extending the amount of time for natural biodegradation. The natural buffering capacity of site soils may mitigate the high pH, as high pH diffuses into water that may contain carbonates or other naturally occurring compounds that can reduce the pH of the groundwater. MNA has the advantage of minimal maintenance, limited monitoring requirements, and limited impact to site operations. Given these benefits and the ease of implementation, MNA has been retained as a technology for further consideration.

# 6.3.1.2 Enhanced Anaerobic Biodegradation

This technology enhances anaerobic biodegradation of organic contaminants by adding nitrate or sulfate to affected groundwater to serve as a terminal electron acceptor. Some site COCs, such as toluene, may act as both a carbon source and an electron donor for certain anaerobic bacteria. In the anaerobic biodegradation process, nitrate is converted to nitrogen gas and the toluene degrades ultimately into carbon dioxide or breakdown products that are assimilated into the biomass. This technology would primarily target toluene at the site.

Implementation of this technology at the site would include injecting a solution containing nitrate into injection wells to areas with high toluene concentrations. Several injections could be required, depending on nitrate demand. Given that a large footprint and some deep areas of the site require treatment, the ability to attain an effective distribution of nitrate to all of the areas with high toluene concentrations is uncertain. Bench scale and, most likely, pilot studies (such as biotraps) would be required to evaluate the effectiveness of this technology at the site and to ensure that biodegradation is occurring. Using nitrate for anaerobic degradation of toluene is also at an early stage in terms of technological development and is not a well proven technology at full scale. This technology may not be very effective for TPH, since anaerobic degradation of TPH progresses very slowly and will need to be evaluated during the bench scale and/or pilot studies. Free-phase TPH areas containing dissolved



toluene could continue to be a long-term residual sources of toluene contamination to the groundwater. For these reasons, this technology was rejected from further consideration.

#### 6.3.1.3 Aerobic Biodegradation

Aerobic biodegradation includes the addition of oxygen into the subsurface either by sparging air into the groundwater or by injecting ORC®. Air sparging involves injection of a compressed gas such as air or oxygen into the contaminated groundwater areas. The compressed gas would be injected into the target area at low flow in order to prevent stripping the VOCs from the groundwater. This low flow will allow for oxygen to diffuse into the groundwater to promote aerobic biodegradation of VOCs and TPH. Oxygen may be released into the subsurface by injection chemicals such as hydrogen peroxide (releasing oxygen as it breaks down) or proprietary blends such as ORC® or Permeox® that slowly release oxygen into the target source areas. Oxygen releasing chemicals and proprietary blends may be injected into the subsurface as a liquid or as a fine powder. The injection of oxygen into the subsurface will allow for oxygen to diffuse into the groundwater to promote aerobic biodegradation of VOCs and TPH. Although aerobic biodegradation has proven effective for dissolved aerobically-degradable organics, this technology has limited effectiveness in remediating COCs in the capillary fringe.

Aerobic biodegradation through the addition of oxygen at the site can either be implemented as an aerobic, biologically-active, flow-through barrier or as a system distributed across the treatment areas. This remediation technology would require numerous injection wells to cover the required treatment areas. Depending on the depth of contamination of the target COCs, the oxygen may also need to be injected under high air pressures. The excess addition of oxygen to the reduced environment at the site will cause iron precipitation to occur within the saturated groundwater formation, which may reduce air flow paths. The effectiveness of the injections at the site will depend on the underlying geology providing oxygen distribution routes for the oxygen to diffuse and be transported throughout the contaminated areas. There is a chance for VOC concentrations in the vadose zone soil gas to increase if the pressure at which air sparging is injected is too high and VOC stripping occurs. Given the benefits and expected efficiency in improving groundwater concentrations for TPH and toluene, air sparging has been retained as a technology for further consideration.

#### 6.3.1.4 Biologically Mediated (Bio-Mediated) Stabilization

Bio-mediated stabilization is accomplished using enhanced biodegradation reactions to produce conditions in which metal contaminants precipitate or co-precipitate with other metals and are immobilized. The technology involves injection of a substrate compound and a source of sulfate into the groundwater to encourage anaerobic biodegradation reactions that generate hydrogen sulfide. The sulfide ion causes metals precipitation, resulting in the stabilization of many metals. A proprietary compound, Metals Remediation Compound, manufactured by Regenesis (San Clemente, CA) or the



proprietary compound by marketed by PeroxyChem, EHC-M<sup>®</sup>, are examples of commercially available products with established pilot-scale and full site implementation success. EHC-M uses zero valent iron to promote reducing conditions to assist in reduction of metals and/or sulfate. These materials can be injected into affected groundwater either as a permeability barrier configuration or distributed over the affected area. Both materials include sulfur generating compounds that would generate hydrogen sulfide which would effectively precipitate metal sulfides. Metals such as arsenic and vanadium will co-precipitate with iron under reducing conditions. The anaerobic biological activity would also promote breakdown of some VOCs.

For the site, bio-mediated stabilization would likely be implemented in a distributed or barrier configuration, depending on the target area. There are significant concerns regarding the cost and effectiveness of using this approach for the site, due to the presence of tidally-influenced marine water and the areas of high pH. The pH in the high pH areas would need to be addressed prior to stabilization of metals. Based on these considerations and the ability of this technology to target deep hot spots in the Shoreline Area for metals; bio-mediated stabilization has been retained for the CMS.

#### 6.3.1.5 In Situ Chemical Oxidation

In situ chemical oxidation involves the injection of oxidants such as ozone, hydrogen peroxide, persulfate, sodium hypochlorite, potassium permanganate, or Fenton's reagent into the target areas in the groundwater to chemically oxidize contaminants. This technology can be highly effective for destruction of organic constituents and may assist with the immobilization of metals through precipitation reactions (notably co-precipitation of arsenate with ferric iron hydroxide). Sufficient oxidant must be added to oxidize the target contaminants and other substances in the groundwater and the aquifer soil matrix, such as reduced metals (ferrous iron and manganese), dissolved organic material, and solid organic material. The presence of other materials that can react with the oxidant either makes *in situ* chemical oxidation less effective at treating COCs or require a much larger oxidant dose. All VOCs and SVOCs that are COCs could be targeted with this technology.

This technology would be implemented at the site through several injection points in areas, including the Uplands Area, with elevated concentrations of targeted COCs. To adequately distribute the oxidant in the groundwater, a large number of injection points or wells would be required to cover impacted areas and depths of the site. High doses of the chemical oxidant would likely be required, as some of the oxidant would be consumed by natural organic matter and high levels of ferrous iron/manganese in the soil and groundwater. The presence of solid materials in the soil (such as buried trees or structures) at the site may increase the oxidant consumption or interfere with the oxidant distribution. Some oxidants (potassium permanganate and hypochlorite) can leave a residual that may have deleterious effects on the environment if not fully consumed. This technology also may require handling large quantities of a hazardous chemical adjacent to an environmentally sensitive



body of water, which creates a potential hazard from spills, leaks, or equipment failure. Based on the capability of *in situ* chemical oxidation to treat small hotspots in groundwater, including the toluene plume on the south east side of the site, the technology was retained for further consideration.

#### 6.3.1.6 In-well Air Stripping

This technology involves air stripping of volatile contaminants within specially designed wells through injection of air into well casings to volatilize contaminants and oxygenate water inside the well. Stripping wells are typically designed with two screened sections. A sparger is placed at the deeper screen and aerated water circulates into the aquifer through the shallow well screen, promoting aerobic biological activity. Vapors generated by the air stripping process are collected from the well casing and directed to an emission control system. In-well air stripping has been successfully documented to reduce volatile organics, and would be applicable to VOCs at the site. Mineral oils, however, would not be effectively addressed by in-well air stripping.

This technology could be implemented at the site in a distributed or barrier configuration. Several stripping wells and vapor removal and control equipment would be required, particularly for a distributed approach. Site groundwater has high reduced iron levels that would be expected to lead to both chemical and bio-fouling of the stripping wells, causing operations problems. Based on this drawback and the limited number of constituents addressed by the technology, in-well air stripping has been rejected from further consideration.

#### 6.3.1.7 Permeable Reactive Barriers

Permeable reactive barriers (PRBs) use a specially designed, permeable barrier designed with reactive media to passively treat groundwater as it flows through the barrier. PRBs are often implemented in a "funnel and gate" approach, in which the PRB is combined with a constructed low-permeability barrier wall to direct groundwater to the gate. A variety of reactive media can be used for PRBs, depending on the specific contaminants to be remediated. Available media include sorptive media (e.g., sorptive clay) or reactive media (e.g., zero-valent iron).

PRBs could be effective for organic and inorganic constituents at the site, depending on the PRB material. This technology can potentially target VOCs and metals, although a single type of gate media would not address both VOCs and metals; thus, successive PRBs may be required to fully address site contamination. The existing barrier wall could serve as the "funnel" for implementation of a funnel and gate approach in the HCIM Area. This technology has the potential to be effective, but would require appropriate operation and maintenance. Given these considerations, PRB technology has been retained for potential use in corrective measures alternatives.



## 6.3.1.8 In Situ Acid Injection

This technology would be used for portions of the Shoreline Area with high pH levels. This technology would be a precursor for metals remediation in the high pH areas of the Shoreline Area where metal COCs exceed PRGs. *In situ* acid injection involves injecting an acid into the subsurface to target areas with high pH. Several different acids may be used to effectively reduce the pH of soil and groundwater, including hydrochloric acid, sulfuric acid, acid salts (e.g., ferrous sulfate), or carbon dioxide. Depending on the alkalinity of the groundwater and the buffering capacity of the soils, a fairly large dose of acid may be required. The pH may also rebound as the injected acid creates a concentration gradient between the soil and groundwater that causes the high pH complexes adsorbed to the soils to diffuse back into the groundwater. One potential issue associated with acid injection is chemical fouling due to precipitation reactions induced by the change in water and soil chemistry. This technology has had limited application, but is the only *in situ* technology available for areas affected by high pH.

In situ acid injection would work at the site as a hot spot treatment method targeting areas with high pH. Several injection points would likely be required to distribute the acid throughout the high pH areas. The injection of acid to control pH has been successful at some sites, both in full-scale and pilot study scales. Effectiveness has varied, and depends on site aquatic and soil chemistry. Due to the presence of compounds associated with high pH that precipitate as the pH reduces (such as silica), it is possible that the injection points and the aquifer matrix could become plugged. A series of follow up injections would likely be required to address the slow rate of reaction of injected acid and the aguifer matrix that contributes to pH rebound. Given these considerations and the need to address high pH in deep groundwater adjacent to the Duwamish Waterway and Slip 6, this technology has been retained. Given that acid injection at the site would need to take place adjacent to the Shoreline Area, it is recommended that carbon dioxide (CO<sub>2</sub>) be used to reduce the risk for environmental impacts. Even if CO<sub>2</sub> injections exceed the equivalent acid requirement for the high pH locations being targeted, the CO<sub>2</sub> will either exit the soil as a gas, take longer to dissolve in solution, migrate farther from the injection point, and/or lower the pH to a much lesser extent than a mineral acid such as hydrogen chloride or sulfuric acid would if overdosed. Injection of CO<sub>2</sub> has not been done at many sites, and primarily has occurred on a pilot scale. To evaluate the effectiveness and safety of using CO<sub>2</sub> injection at the site, a pilot study will be used. For more details on the pilot study see Appendix D.

#### 6.3.1.9 Thermal Remediation

Application of this technology involves injecting steam into the aquifer or installing electrodes into the aquifer and applying a current to heat up the subsurface, increasing the volatility of organic compounds to release them into the soil gas phase. In order to treat the soil gas, this technology is used in conjunction with SVE to recover the steam and volatile organics. Thermal treatment has proven partially effective at some sites, but it requires extensive monitoring and careful management



to confirm effectiveness and to prevent COC plume migration into previously unaffected areas, from the condensation of the contaminated soil gas or through the release of contaminates that were previously sorbed to silts or organic carbon. A review of application history indicates that numerous failures in prior applications have been documented.

Application at the site would require numerous wells and high steam requirements or numerous electrode installation points and high electrical requirements, based on the depth and areal extent of affected groundwater. Soil gas recovery may prove difficult, given the presence of substructures such as building foundations, basements, old utilities, and buried trees. Steam would sterilize site soils, causing cessation of natural biodegradation processes. A full site demolition would be required for controllable application. Given the history of process implementation and control problems combined with the logistics of application at the site, thermal remediation was rejected from further consideration for the site.

### 6.3.2 Ex Situ Groundwater Remediation Technologies

Ex situ groundwater remediation technologies rely on a pump-and-treat approach to remove mass from the groundwater by recovering affected groundwater and treating it in an appropriately designed treatment plant. Treated water would be either discharged to a publicly owned treatment works or to surface water under a National Pollutant Discharge Elimination System (NPDES) permit. This technology removes contaminant mass from areas where pumping is conducted. While ex situ treatment can be done either on site or off site, only on-site remediation has been considered for the site, due to the large volume of affected groundwater.

A mass recovery and pump-and-treat system for the site would need to be designed to treat the COCs being recovered by the extraction wells. Components of a pump-and-treat system may consist of a bioreactor (either aerobic or anaerobic) to address organics; adsorbents to address either organics or inorganics; an advanced chemical oxidation process to address organics; air strippers to address VOCs; ion exchange media to address inorganics; filtration to remove particulates; acid neutralization to address high pH groundwater; or a precipitation, coagulation, and flocculation process. All of the technologies that could be considered applicable in a pump-and-treat system are discussed in Table 6-4. Considering the long term maintenance required and the length of time the mass removal would take to clean up the entire site, mass recovery is retained only for the Shoreline Area as a hot spot treatment technology.

#### 6.3.3 Physical Containment Technologies

Containment technologies are often implemented to collectively address soil and groundwater contamination. These technologies isolate affected media and prevent, or significantly reduce, the generation and subsequent migration of contaminated groundwater. Containment technologies for



groundwater include capping the soils above affected groundwater and installing a low permeability barrier wall around an area of affected soil or groundwater. Capping minimizes infiltration of surface water through the affected soils that may potentially contaminate the underlying groundwater. Low-permeability barrier walls can prevent or minimize migration of affected groundwater.

### 6.3.3.1 Impermeable Caps

Capping involves placement of a low-permeability asphalt or multi-layer soil-based cap above soils overlying affected groundwater to minimize infiltration and the potential for generating additional groundwater contamination through infiltration of rainwater. While applicable to all contaminant types, capping does not destroy or reduce overall contaminant mass, but focuses on removing one potential route for future contaminant migration. Caps also limit the potential for direct exposure to affected groundwater.

Capping has a well established performance record for reducing surface water infiltration, and has been implemented for portions of the site. This technology addresses all COCs at the site. Capping would be an effective supporting technology to improve overall effectiveness of other technologies. Capping has been retained as a technology for potential combination with other technologies as part of the corrective measures alternatives.

#### 6.3.3.2 Barrier Walls

Low-permeability barrier walls, typically constructed of soil/bentonite, sheet piles, or grout, can be highly effective in limiting migration of affected groundwater and in minimizing the volume of groundwater to be recovered in order to establish hydraulic control. A barrier wall consisting of a proprietary mixture of attapulgite clay and fly ash (called Impermix ®) has been installed around the HCIM Area and is used in conjunction with a groundwater recovery and treatment system that has proven to be effective in establishing and maintaining hydraulic control for the most highly contaminated site groundwater. Based on successful performance of the existing barrier wall, this technology has been retained.



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# 7.0 DEVELOPMENT AND EVALUATION OF CORRECTIVE MEASURES ALTERNATIVES

Remedial technologies for soil or groundwater that are feasible for the site were identified as detailed in Section 6 using a two-step screening process, consistent with EPA RCRA Corrective Action Plan guidance (EPA, 1994). The first step was to identify potentially applicable remedial technologies appropriate for site COCs that have been proven in full-scale applications or that have been used in pilot-scale programs and appear to be potentially feasible for use at the site. The feasible remedial technologies have been used to develop the corrective measures alternatives described in Section 7.1. Corrective measures alternatives have been developed for each corrective measures area identified for the site. The alternative conceptual designs will be developed in the CMS.

The alternatives will be evaluated for each area to identify the preferred alternative for each area, which will then be combined to identify the preferred corrective measure for the site. The evaluation will also consider the ICs, as described in WAC 173-340-360(2)(e), and ICs will be proposed as a component of each of the alternatives in the CMS. ICs are not a remediation technology and do not result in site cleanup, rather they are commonly used as a component of remedial alternatives to address residual soil and/or groundwater contamination. In addition, ICs may be used to protect human health and the environment during implementation of a remediation program that may require longer time frames to achieve remediation objectives. ICs typically consist of administrative controls, such as deed restrictions and controls that prohibit actions that may result in the exposure of individuals to soil or groundwater contaminants. They may also include engineering controls that limit exposure to individuals and the environment (e.g., soil cover, hydraulic control, and site fencing).

ICs can include deed restrictions to protect the health and safety of people who may come in contact with the site in the future. Such restrictions could include preventing or limiting site excavation work, requirements to notify future construction workers of the presence and location of affected site soil or groundwater, or precluding future use or redevelopment of the property for certain uses, such as residences, schools, day care centers, or hospitals. ICs can also establish requirements for new construction to address sealing or ventilation of concrete slabs, thereby reducing exposure to potentially harmful VOCs through the vapor intrusion pathway. Additional ICs can be established to maintain remediation technologies put in place at a site. ICs may only work for a property that is owned and/or operated by the responsible party where enforceable controls can be established. If the property is not owned or operated by the responsible party, it may be difficult to implement ICs due to the requirement to negotiate with the neighboring property owners. Even if agreements can be reached with the neighboring property owners, it may be difficult to enforce ICs on property that is not owned by the liable party. Public notices, zoning overlays, or similar means may be employed when the responsible party is unable to obtain restrictive covenants on property not owned by the responsible party (following a good-faith effort in accordance with WAC 173-340-440[8][c]).



Administrative controls can also be non-enforceable restrictions that provide information, notification, or site security. These controls may include the installation of warning signs that inform users of the potential site hazards and access requirements. On-site security and containment fencing may be employed in addition to warning signage to prevent unauthorized individuals from entering the property. On an industrial facility operation, administrative controls can be built into site safety plans and in employee and visitor hazard communications.

The corrective measures alternatives evaluation approach is described in the following subsections.

## 7.1 CORRECTIVE MEASURES ALTERNATIVES

The retained technologies listed in Table 6-1 have been incorporated into corrective measures alternatives for the remediation areas: the HCIM Area, the Uplands Area, the Shoreline Area, and the Sediment Area. These four areas are shown on Figure 1-2. The Sediment Area will be remediated as specified in the Proposed Plan, Lower Duwamish Waterway Superfund Site (EPA, 2013); no corrective measures alternatives will be developed or evaluated for the area outside of the property.

#### 7.1.1 Sediment Area Alternative

The EPA outlined the remediation alternatives that were considered for the Lower Duwamish Waterway Superfund Site, which includes the Sediment Area, in the Proposed Plan (EPA, 2013). The remediation alternative identified in the Proposed Plan for implementation within the Lower Duwamish Waterway provides for a combination of ENR, capping, dredging, and removal of creosote pilings. This approach must be implemented for the Sediment Area. As the Sediment Area consists of an intertidal area, the corrective measure to be implemented consists of dredging affected sediments, disposal of dredged sediments at a permitted, off-site landfill, and restoration of the dredged area using an appropriate fill material. Another component of the Sediment Area corrective measure includes removing the existing creosote piles present in the Sediment Area.

## 7.1.2 HCIM Area Alternatives

The HCIM Area includes the most highly contaminated portions of the site. Most of the historical operations, including manufacturing, shipping/receiving, and bulk chemical storage, occurred within this area. Affected groundwater and soil within the HCIM Area have been substantially contained by installation of a low-permeability subsurface barrier wall and surface pavement. Previous interim measures have removed a substantial quantity of contamination. As indicated in the corrective measure objectives presented in Section 4.2, the alternatives considered for potential implementation within the HCIM Area should be compatible with the barrier wall unless an alternate approach is included to comprehensively address the large volume of contaminated soil and groundwater. Alternatives for the HCIM Area are outlined below. Although not explicitly noted for each alternative,



ICs such as deed restrictions, restricted site access and use, and other administrative controls will be a component of all four HCIM Area alternatives, as contaminants would remain within the area after completing remediation.

#### 7.1.2.1 Alternative HCIM-1

Alternative HCIM-1 consists of active hydraulic containment of the HCIM Area by maintaining the existing barrier wall, surface cover, and groundwater recovery system. No additional corrective actions are included in this alternative. Continued maintenance and monitoring will be included. Alternative HCIM-1 would not clean up all COCs within the barrier wall, but would continue to contain all COCs and provide time for MNA to progress.

#### 7.1.2.2 Alternative HCIM-2

Alternative HCIM-2 consists of *in situ* stabilization of the soils in the HCIM Area through deep soil mixing and placement of a pavement cover over the stabilized area. Large soil mixing augers would be used to mix affected soil and groundwater with an additive such as Portland cement. Mixing would extend to the depth of affected soil/groundwater. Excess "fluff material" generated from this alternative would be removed for off-site disposal. It is expected that this alternative would result in destruction of the existing barrier wall and all wells located within the HCIM Area. Alternative HCIM-2 would not result in the cleanup of any COCs but would permanently bind the metals and some SVOCs in the subsurface. Also, the reduction in permeability would reduce flow through the HCIM Area and provide more time for natural attenuation of VOCs such as toluene.

## 7.1.2.3 Alternative HCIM-3

Alternative HCIM-3 relies solely on passive hydraulic containment of the HCIM Area by maintaining the existing barrier wall and surface cover. No active groundwater recovery is included in this alternative; containment is provided by the low-permeability barrier wall, with surface water infiltration limited by surface cover. Continued maintenance and monitoring will be included. Alternative HCIM-3 would not clean up all COCs within the barrier wall area but would rely on passive containment for all COCs and provide time for monitored natural attenuation to progress.

#### 7.1.2.4 Alternative HCIM-4

Active groundwater recovery is not used for this alternative HCIM-4. Groundwater would flow from the HCIM Area via a "gate" through the barrier wall located on the upgradient side of the area (southeast corner of the HCIM Area). A PRB, such as a barrier of aerated sparge wells, would be used to promote active degradation of mobile organic constituents prior to discharge through the gate. Groundwater would flow passively from the HCIM Area via a gap created in the barrier wall and natural attenuation would reduce contaminant concentrations as groundwater flows to the gate and



then out into the Duwamish Waterway or Slip 6. Alternate PRB designs may be considered for the CMS depending on COCs. The rest of the barrier wall and surface cover would remain intact for this alternative. This alternative would be designed to address all COCs within the HCIM Area, including removal of metal media and aerobic remediation for the VOCs. High pH groundwater would attenuate naturally as the high pH groundwater in the southwest corner of the site would flow across the entire site and contact carbonates along the flow path to buffer the groundwater.

# 7.1.3 Uplands Area Alternatives

The Uplands Area consists of the areas to the north and east of the HCIM Area (Figure 1-2). As noted previously, the only portion of the Uplands Area requiring remediation consists of soil and groundwater affected by toluene near the southeast corner of the property. Three alternatives will be considered for this area, as outlined below:

## 7.1.3.1 Alternative UA-1

Alternative UA-1 includes continued use of the biosparge system to bioremediate the toluene plume and volatilize toluene in the overlying impacted soil. The biosparge system has reduced the size and concentration of the toluene plume, but has not achieved PRGs.

## 7.1.3.2 Alternative UA-2

Alternative UA-2 includes hot spot excavation and off-site disposal of the contaminated toluene soils in the southeast corner of the Uplands Area and MNA to address affected groundwater.

#### 7.1.3.3 Alternative UA-3

Alternative UA-3 consists of contaminated soil excavation/off-site disposal and injection of chemical oxidant into toluene hot spots to chemically oxidize remaining groundwater contaminants.

#### 7.1.4 Shoreline Area Alternatives

The Shoreline Area consists of the shoreline with the Duwamish Waterway and Slip 6 (Figure 1-2). The Shoreline Area includes an area of high pH in the southwest corner of the property and areas affected by other COCs, including metals and organics. As noted below, the corrective measures alternatives being considered for the Shoreline Area include excavation of soil hot spots and neutralization of the area with elevated pH levels. If determined to be appropriate during the CMS, the Shoreline Area may be restored to enhance shoreline habitat. If habitat enhancement is determined to not be appropriate, the Shoreline Area will be restored to the present configuration after completing remediation. Due to limited use of acid injection for neutralizing areas with high pH in a marine environment, a site-specific pilot study is planned to assess the effectiveness of the technology and to



collect site-specific design data, as discussed in more detail in Section 8. The Shoreline Area corrective measures alternatives are outlined below.

#### 7.1.4.1 Alternative SA-1

Alternative SA-1 includes excavation on the Duwamish Waterway side of the Shoreline Area. The excavation would target soil hotspots for COCs and would be followed by placement of a low-permeability surface cover as part of site restoration. The low permeability cover would limit surface water infiltration. Natural recovery would address groundwater COCs for the Shoreline Area under this alternative.

## 7.1.4.2 Alternative SA-2

Alternative SA-2 consists of soil hotspot excavation on the Duwamish Waterway side similar to Alternative SA-1, restoration, and *in situ* treatment. *In situ* treatment would consist of injection of an acid into the high pH areas to reduce the pH to a level conducive to biological degradation of COCs. After high pH areas have been neutralized; additional injections would be implemented, consisting of sulfate-containing substrate and possibly zero valent iron to promote anaerobic biodegradation of the substrate/organic COCs and immobilization of metals as the metals precipitate with sulfides or co-precipitate with other metals (arsenic and vanadium with iron).

## 7.1.4.3 Alternative SA-3

Alternative SA-3 consists of targeted mass removal from the groundwater with an *ex situ* pump and treat system. In this alternative, either existing monitoring wells would be used or new wells would be installed in areas of high COC mass and pumped to reduce the mass in the groundwater. The groundwater recovered would be treated and discharged either to the sanitary sewer with a permit or to surface water with an NPDES permit.

# 7.2 EVALUATION OF THE CORRECTIVE MEASURE ALTERNATIVES

A preliminary screening process for selection of feasible corrective measure technologies identified technologies expected to be effective for addressing soil and groundwater remediation (Section 6). The corrective measures alternatives described in Section 7.1 were developed to be consistent with Appendix C of the Order and EPA Corrective Action Plan guidance. These corrective measures alternatives will be screened in the CMS using the following evaluation criteria: technical; environmental; human health; institutional needs; cost; restoration timeframe, and green remediation. Each criterion will then be ranked low, medium, or high based on the alternative's ability to address the criteria as outlined below. A conceptual design will be developed for each alternative to support cost estimation and to generally describe the potential implementation of each alternative.



## 7.2.1 Technical

The technical evaluation considers the performance, reliability, implementability, and safety for the alternatives. Performance will be evaluated by considering the effectiveness of the alternative in performing the intended remediation functions and the length of time the level of effectiveness may be maintained. The reliability of each alternative considered for the site will focus on the magnitude of the operation and maintenance requirements needed to sustain long term effectiveness and the complexity involved to maintain each alternative. The reliability of the alternative also will depend on the demonstrated and expected reliability based on the technology's track record under similar conditions and the potential for failure. The implementability of the alternative includes the constructability of the alternative, the ease of installation, and the time required to construct the remedy and achieve a given level of risk reduction. Finally, worker and community safety during implementation and operation of the alternative will be assessed. The evaluation of safety will consider the potential for exposure of workers and/or the community to hazardous substances and other factors that may threaten the safety of site workers.

The scoring system for the technical screening criteria will be based on each alternative's:

- 1. Performance, including effectiveness and useful life;
- 2. Reliability, considering operation and maintenance along with the demonstrated and expected reliability;
- 3. Implementability, including constructability and time to implement the technology and see beneficial results; and
- 4. Safety of nearby communities, workers, and the environment.

Depending on how well the alternative addresses each of the points outlined above, the alternative will be rated low, medium, or high for the technical criteria.

## 7.2.2 Environmental

The environmental evaluation will focus on exposure pathways addressed by each alternative and the effects on facility conditions. In summary; the environmental assessment will consider the short and long term beneficial and adverse effects on environmentally sensitive areas such as the Lower Duwamish Waterway, with a complete analysis of the necessary measures to mitigate the adverse effects.

The scoring system for the environmental criteria will consist of rating each alternative as low, medium, or high based on the alternative's ability to address environmental exposure pathways, both short and long term.



#### 7.2.3 Human Health

The human health evaluation will be based on an assessment each alternative for the extent to which the alternative mitigates both short and long term exposures of the public to contamination during and after the implementation of the technology. The assessment will consist of an evaluation of the remaining level of exposure and the reduction in contaminants achieved by the alternative over time.

The scoring system for human health will be based on the ability of each alternative to:

- 1. Provide short and long-term beneficial effects;
- 2. Minimize adverse effects;
- 3. Address potential exposure routes; and
- 4. Reduce the potential for exposure to the potentially affected populations.

Depending on how well the alternative addresses each of the points outlined above, the alternative will be rated low, medium, or high for the human health criteria.

# 7.2.4 Institutional Needs

The institutional evaluation will assess the effects of federal, state, and local environmental and public health standards, regulations, guidance, advisories, ordinances, or community relations on the design, construction, operation, and timing of each alternative.

The scoring system for Institutional requirements will be based on the alternatives acceptance by:

- 1. The public; and
- 2. All applicable regulatory agencies.

Depending on how well each alternative addresses the points outlined above, the alternative will be rated low, medium, or high for the institutional criteria.

## 7.2.5 Cost

Each alternative will be evaluated for the cost of engineering, implementation, life cycle operation/maintenance, and long-term monitoring. These cost estimates will be prepared using published cost estimating tables, empirical data, vendor information, and professional engineering judgment. The costs will include future costs for the estimated restoration time of the specific alternative or a maximum life of 30 years, whichever is less. This rough, conceptual level cost estimate will be based on a conceptual design of each alternative for each corrective measures area. The conceptual design and conceptual level cost estimates for all alternatives considered will be



approximately equivalent in detail and accuracy. Summary tables will be provided for each alternative with more detailed estimates included as an appendix to the CMS report. A brief summary of the implementation costs, operating, maintenance, and monitoring costs are discussed below.

# 7.2.5.1 Implementation Costs

The costs for implementing an alternative include capital costs associated with purchase of facilities, equipment, building or utility relocation, and/or permanent construction plus expenses associated with these activities, including engineering. Implementation costs typically occur at the beginning of the implementation program, but may include costs that occur later in the remediation program, such as replacement of key remedial system components that are needed over the operating life. Each corrective measures alternative will be reviewed to identify implementation costs. These costs will be estimated in dollars that are current at the time the estimate is made. Engineering and construction costs will be estimated using published cost factors for major construction items and typical multipliers or contingencies for minor items associated with implementation of specific alternatives.

# 7.2.5.2 Operating, Maintenance, and Monitoring Costs

Operating and maintenance costs include longer term expenses associated with multi-year remediation activities. Monitoring costs are typically associated with most remedial actions to prove that the implementation has been effective, with monitoring periods potentially ranging from less than one year to many years. Operations costs will include labor, power, and consumed materials associated with routine operation of systems. Maintenance costs include labor and material for periodic preventative maintenance recommended by equipment manufacturers or for replacement of failed equipment. Monitoring costs include sampling labor, sampling equipment and supplies, laboratory analysis, and reporting costs. Monitoring costs will include costs associated with any verification sampling conducted at the end of the implementation period to document that the alternative attained the cleanup standard.

# 7.2.5.3 Present-Worth Analysis

A single present-worth cost will be presented for each remedial alternative considered for the three remediation areas. The present-worth cost will be the sum of the initial implementation cost and the net present value for future costs (i.e., operating, maintenance, monitoring, managing, and any implementation costs occurring in the future). The assumed net discount rate that will be used for calculating the net present value is 1.5 percent; present worth calculations will be documented in an appendix to the draft CMS report. The present-worth cost will be used to compare costs for the alternatives. The costs for the cleanup alternatives will be compared to the benefits that would result from implementation of the alternative to assess any disproportionality of costs and benefits.



The estimated cost are intended to be used for relative cost comparison, and solely as a decision tool and not a planning tool for construction of the alternative.

## 7.2.6 Restoration Timeframe

In addition to the criteria outlined above, each alternative will be evaluated for the estimated restoration timeframe. Restoration timeframe is defined as the time needed to achieve corrective measures objectives. The following factors will be considered for each remedial alternative:

- Potential risks of the specific area to human health and the environment under conditions prior to completion of the alternative;
- Practicality of implementing the alternative within a shorter timeframe;
- Present and future land use for the site, including any constraints land use may have on the alternative;
- Present and potential for future use of any water resources either associated with or that may be affected by the area in consideration;
- The availability of alternative water supplies, if appropriate;
- Potential effectiveness and reliability of any ICs associated with the alternative;
- The ability of the alternative to limit and monitor migration of COCs;
- Toxicity of COCs associated with the CMS area; and
- Efficacy of any natural processes that may mitigate the impact of COCs associated with the CMS area.

The alternatives will be assessed relative to attainment of these factors. The alternative with the shortest estimated restoration time will be ranked highest and the alternative with the longest restoration time will be ranked lowest.



## 7.2.7 Green Remediation

Each alternative will be evaluated through the consideration of the opportunities to implement green remediation at the site as part of the remedial design, remedial construction, operation and maintenance, and long term monitoring. Green remediation consideration consists of six core elements that will be considered while evaluating the alternatives outlined above: energy, air, water, land and ecosystems, materials and waste, and stewardship. Consideration of these six core elements together will minimize the environmental impacts of the remediation process. The following factors will be considered for each remedial alternative:

- Energy requirements, such as little to no demand for external utility power, energy efficient equipment, potential for renewable energy systems, and optimization of energy efficiency over time.
- Air emissions, including minimizing vehicle emissions and dust during remediation activities, and considering overall reduction in atmospheric releases of toxic or priority pollutants.
- Water requirements and impacts on water resources, such as minimizing fresh water consumption and maximizing re-use of water resources, while considering nutrient loading to adjacent waterways such as the Duwamish Waterway.
- Land and ecosystem impacts, looking at minimally invasive alternatives, passive energy technologies that may be used with each alternative, minimizing soil and land disturbance, and reduction in noise and lighting disturbances.
- Material consumption and waste generation, including looking at alternatives that may
  employ technologies that minimize waste and have the opportunities to re-use materials
  and recycle materials used at the site, while minimizing the amount of natural resources
  required.
- Long-term stewardship actions, evaluating the ability of alternatives to reduce air emissions for greenhouse gases, the ability for each alternative to use renewable energy systems to power the remediation components long term, and adaptive management.

Each alternative will be assessed based on the ability of the alternative to address as many of the factors outlined above and in EPA's guidance documents for green remediation including but not limited to the guidance provided on the Contaminated Site Clean-Up Information website. The alternatives with the highest potential to address the factors outlined above and in EPA's guidance documents for green remediation will be ranked high and the alternatives with the least potential to address the factors will be ranked low.

## 7.3 Preferred Corrective Measure

Once each alternative has been evaluated for technical, environmental, human health, institutional needs, cost, restoration time frame, and green remediation criteria, the alternative with the highest



relative ranking and for which the benefits are not disproportionate to costs will be recommended as the corrective measure for the site. The final justification will be presented in a table summarizing the trade-offs among the evaluation criteria and any other pertinent factors. Once a final alternative is selected, the final recommendation will be made and a conceptual level cost will be presented including the cost for the Sediment Area remedy.



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## 8.0 PILOT STUDIES

As part of the CMS, pilot testing will be performed to support development and evaluation of the corrective measures alternatives for the Shoreline Area that include injection of acid to neutralize the areas affected by high pH. Pilot studies will be performed to collect design and cost information, and to assess the effectiveness of promising corrective measure technologies for inclusion in the corrective measures alternatives. Based on review of site-specific considerations that will affect cleanup actions (Section 5) and corrective measure technologies (Section 6), pilot testing will be performed for injection of CO<sub>2</sub> to neutralize high pH areas. CO<sub>2</sub> injection will allow for a greater distribution of acid throughout the water column when compared to other liquid acids, as the gas will be able to migrate more readily through preferential flow paths and around impermeable areas. In addition, an overdose of CO<sub>2</sub> in the environment outside the wall will not have as profound of an effect as other acids, such as sulfuric or hydrochloric acid. The general plan for pilot testing of CO<sub>2</sub> injection is outlined below. A detailed pilot study work plan is included as Appendix D. The schedule anticipated for pilot testing is discussed in Section 10 of this work plan. As noted in Section 10, the time required for pilot testing may be extended, depending on actual site conditions and the rate of pH rebound.

## 8.1 PILOT STUDY OBJECTIVES

The objectives for the CO<sub>2</sub> injection pilot study are as follows:

- 1. Estimate CO<sub>2</sub> consumption to achieve neutralization.
- 2. Evaluate CO<sub>2</sub> utilization efficiency at different injection rates.
- 3. Evaluate CO<sub>2</sub> injection rates at different pressures and effect of precipitation on injection rate.
- 4. Evaluate the radius of influence for CO<sub>2</sub> injection at different injection rates.
- 5. Assess effect of CO<sub>2</sub> injection on groundwater chemistry and resulting precipitation.
- 6. Assess pH rebound after CO<sub>2</sub> injection.

These objectives support evaluation of the effectiveness of CO<sub>2</sub> injection in achieving neutralization objectives and provide information needed for the conceptual design needed to complete the CMS. The results of the pilot testing must be applicable to the high pH portion of the Shoreline Area.

# 8.2 PILOT STUDY OVERVIEW

Pilot testing will be conducted for injection of gaseous CO<sub>2</sub> into areas impacted by high pH to reduce the pH to below 8.5. Pilot testing will be conducted inside the barrier wall instead of in the Shoreline Area, to reduce the potential of adverse impacts to adjacent surface water. It is expected that



groundwater chemistry and soil composition within the high-pH areas inside the barrier wall will be similar to conditions within the Shoreline Area, outside the barrier wall. Therefore, pilot testing will be conducted using MW-54 for CO<sub>2</sub> injection, as MW-54 is screened across similar depths and strata as MW-43 outside the wall and had a high pH as measured in 2014 (Figure 8-1). Well MW-54 is located about 8 feet from MW-53 and approximately 13 feet from the barrier wall. Thus, the effect of the barrier wall on CO<sub>2</sub> injection will be similar to its effect during Shoreline Area injections. Well MW-53 is completed in the shallow portion of the upper aquifer, and has a pH of 10.79 (slightly lower than the pH observed in the MW-43/MW-44 well cluster). MW-53 will be used as an observation well. MW-54 is located about 40 feet from the MW-43/MW-44 well cluster. MW-54 is completed in the deep portion of the upper aquifer and has a pH of 10.52. MW-54 is also located near the edge of the high pH area, which will support evaluating effects of injection on areas with lower pH levels.

Pilot testing will be performed by injection of CO<sub>2</sub> into the injection well and measuring the effects of CO<sub>2</sub> neutralization and resulting pressures in observation wells located at different distances from the injection well. One well (MW-29) is completed near the top of the shallow aquifer unit and is approximately 37 feet north of MW-54; this well currently has a pH of 6.78, which is typical of site groundwater unaffected by caustic soda. As mentioned above, MW-53 is located 8 feet from MW-54 with a pH of 10.79 as measured in 2014 and will be used as an observation well. All other nearby wells are located more than 100 feet from the proposed pilot testing wells. Therefore, it will be necessary to install additional observation wells near MW-54 to observe the effects of neutralization. The approximate locations of these additional CO<sub>2</sub> monitoring wells are shown on Figure 8-1.

In order for neutralization to be effective, both groundwater and soil must be neutralized. It is expected that long-term exposure of site soils to high pH groundwater has altered soil surface chemistry. Since the reaction kinetics for surface reactions are typically much slower than aqueous reaction kinetics, it is also expected that substantial rebound in pH will occur after groundwater has been neutralized. The buffering capacity of the soil and the alkalinity of the groundwater must be neutralized in order to achieve neutralization objectives. Soil and groundwater samples will be collected during installation of observation wells to obtain data for soil and groundwater alkalinity. The water samples will also be used to assess precipitation caused by reducing the groundwater pH.

Details for the planned pilot study are presented in the Pilot Study Work Plan (Appendix D). As noted in the Pilot Study Work Plan, testing will be conducted to characterize the radius of influence achieved by different injection rates. Measured radius of influence information will be used to design injection well spacing for CO<sub>2</sub> injection within the Shoreline Area. Pilot testing also will be directed toward determining the effect of the injection rate on utilization of the CO<sub>2</sub>. In order for CO<sub>2</sub> to neutralize the high pH, the CO<sub>2</sub> must dissolve into the water. It is expected that high CO<sub>2</sub> injection rates will cause gaseous CO<sub>2</sub> to bubble through the water column or form subsurface channels, resulting in release to



the vadose zone and, ultimately, to the atmosphere; any CO<sub>2</sub> released to the vadose zone would not be utilized for neutralization of caustic soda. A vent well is included in the pilot study design to measure CO<sub>2</sub> passing through the vadose zone. The pilot study injection test plan outlined in Appendix D is designed to attain the objectives discussed above. It is anticipated that well MW-54 will be used as an injection point over the duration of the pilot study. The pilot study will be set up to allow for a change in injection pressure and a corresponding change in the injection flow rate.

The radius of influence of each injection flow rate will be measured and the CO<sub>2</sub> utilization efficiency will be monitored. The study will begin with a low injection flow rate by injecting CO<sub>2</sub> at the minimum pressure (the sum of hydrostatic pressure at the top of the well screen and the formation entry pressure) and allowing the CO<sub>2</sub> to diffuse into the groundwater during the first injections. The flow rate will be increased by increasing the injection pressure in a series of steps and assessing the change in radius of influence as the flow rate is increased. During injections; the pressure in the observation wells will be monitored to determine steady-state conditions for each the injection step, as well as to evaluate mounding and the radius of influence. The pH of the observation wells will also be monitored to evaluate the radius of influence and neutralization kinetics. Once the system is saturated with carbonic acid at the highest flow rate tested (defined as the maximum obtainable pressure without fracturing the formation) and the gas sparging has ceased, the system will be monitored for pressure and pH to evaluate mounding and pH rebound from the soil kinetics. It is anticipated that pilot study equipment requiring electricity will be located near the groundwater pretreatment building and that piping/tubing will be run to the test wells along fencing.

Each monitoring point shown on Figure 8-1 and discussed above will be sampled for pH to evaluate the change in pH as changes in the CO<sub>2</sub> injection system are made and to evaluate pH rebound. Groundwater chemistry will be evaluated before initial injections, after each round of injections, and after the final injections to determine changes in chemistry from injections of CO<sub>2</sub>. Pressure in the monitoring locations will be monitored to determine the effects of injection of a gas into the groundwater and to determine the radius of influence and effects of groundwater mounding on injection cycles. The total CO<sub>2</sub> flow rate and total flow will be monitored and recorded for each injection flow rate. Aquifer and well conditions also will be monitored before initial injections are conducted and after the final injection is completed. For more details on the CO<sub>2</sub> injection procedure, see the CO<sub>2</sub> Injection Pilot Study Work Plan in Appendix D.



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## 9.0 PROPOSED CMS REPORT OUTLINE

The CMS report will be prepared in accordance with the requirements of the Order and EPA guidance. The report will document the work performed in completing the CMS and present the results. The proposed outline is presented below. This proposed outline may be modified somewhat during report preparation; however, the major sections shown below will be retained.

- 1. Introduction
  - a. Background
  - b. Purpose and Goals
  - c. CMS Approach and Report Organization
- 2. Current Conditions
  - a. Historical Site Uses
  - b. Hydrogeological Setting
  - c. Previous Investigations
    - i. Soil Investigations
    - ii. Groundwater Investigations
  - iii. Sediment/PoreWater Investigations
  - d. Interim Remedial Measures
    - i. PCB Removal
    - ii. Soil Vapor Extraction
  - iii. Hydraulic Control Interim Measures
- 3. Media Cleanup Criteria and Constituents of Concern
  - a. Preliminary Cleanup Levels
    - i. Preliminary Soil Cleanup Levels
    - ii. Preliminary Groundwater Cleanup Levels
    - iii. Preliminary Sediment Cleanup Levels
  - b. Constituents of Concern
    - i. Soil Constituents of Concern
    - ii. Groundwater Constituents of Concern
    - iii. Sediment Constituents of Concern
- 4. Source Areas and Potential Exposure Pathways
  - a. Corrective Action Areas
    - i. HCIM Area
    - ii. Uplands Area
    - iii. Intertidal/Shoreline Area
  - b. Conceptual Site Model
    - Overview
    - ii. HCIM Area Exposure Pathways
  - iii. Uplands Area Exposure Pathways



- iv. Intertidal/Shoreline Exposure Pathways
- 5. Corrective Measures Objectives and Screening Criteria
  - Corrective Action Objectives
    - Overall Objectives
    - ii. HCIM Area Objectives
  - iii. Uplands Objectives
  - iv. Intertidal/Shoreline Objectives
  - b. Corrective Measures Screening Criteria
    - i. Technical Criteria
    - ii. Human Health Criteria
    - iii. Environmental Criteria
  - iv. Institutional Criteria
  - v. Cost
- 6. Remediation Technologies Screening
  - a. Potentially Applicable Remediation Technologies
  - b. Detailed Screening of Technologies
  - c. Retained Remediation Technologies
- 7. Potential Corrective Measures, HCIM Area
  - a. Description of HCIM Area Alternatives
  - b. Screening of HCIM Area Alternatives
  - c. Preferred HCIM Area Alternative
- 8. Potential Corrective Measures, Uplands Area
  - a. Description of Uplands Area Alternatives
  - Screening of Uplands Area Alternatives
  - c. Preferred Uplands Area Alternative
- 9. Potential Corrective Measures, Intertidal/Shoreline Area
  - a. Description of Intertidal/Shoreline Area Alternatives
  - Screening of Intertidal/Shoreline Area Alternatives
  - c. Preferred Intertidal/Shoreline Area Alternative
- 10. Evaluation of Preferred Site-wide Corrective Measure
  - a. Preferred Site-wide Corrective Measure Alternative
  - b. Detailed Evaluation
    - i. Technical
    - ii. Human Health
    - iii. Environmental
  - iv. Institutional
  - v. Cost
  - c. Conclusions and Recommendations



# 10.0 PROJECT MANAGEMENT PLAN

This section presents the project management plan for the CMS and describes the procedures to be followed to ensure the CMS is prepared in accordance with requirements specified in the Order and to meet EPA's expectations. The project management plan presents the overall project management approach, defines levels of authority of key personnel, illustrates lines of communication between project team members, presents the proposed project schedule and budget, and describes roles, responsibilities, and qualifications for personnel directing or performing the work. This project management plan will be reviewed and revised if necessary.

## 10.1 OVERALL PROJECT MANAGEMENT APPROACH

The overall project management approach is shown in Figure 10-1, which specifies roles of key personnel and summarizes lines of communication between project team members. Project personnel roles, responsibilities, and qualifications are described below.

Gary Dupuy, LG, LHg, Principal Hydrogeologist for AMEC, is the respondent's Project Coordinator designated in the Order. He is responsible for overseeing implementation of the Order and as such is responsible for overseeing preparation of the CMS and verifying the CMS is prepared in accordance with the Order. Mr. Dupuy is a licensed hydrogeologist in Washington State, with more than 30 years of experience managing assessment and remediation of contaminated properties. Mr. Dupuy earned a BS in geology from the University of Alberta.

Larry McGaughey, PhD, PE, Senior Associate Engineer, will be project manager for the CMS. He will serve as technical director and lead engineer, and will supervise personnel conducting the CMS. Dr. McGaughey is responsible for overseeing day-to-day completion of the CMS and has the full authority to assign staff and execute actions necessary to ensure that the CMS is performed in accordance with the Order and applicable regulatory requirements, and that it is technically sound. McGaughey is a licensed engineer in Washington State and has more than 35 years of experience characterizing and remediating contaminated properties. Dr. McGaughey earned his PhD in environmental engineering from the University of Houston.

Koorus Tahghighi, PE, Associate Engineer, will provide project QA/QC and serve as senior civil engineer. As QA/QC officer, he will provide senior review of the CMS report, including conceptual designs and cost estimates. As senior civil engineer, he will work directly with junior engineers to develop and evaluate conceptual designs for corrective measures alternatives and to develop cost estimates. Mr. Tahghighi has more than 28 years of civil engineering experience specializing in engineering solutions for environmental remediation projects. Mr. Tahghighi is a licensed engineer in Washington State and earned an MS in geotechnical engineering from Drexel University.



John Long, LG, LHg, Associate Hydrogeologist, will serve as senior hydrogeologist. He will lead the hydrogeologic evaluations in support of the CMS. He will perform hydrogeologic and geologic analyses, analyze data, and prepare reports and supporting material as directed by the project manager. Mr. Long has more than 25 years of experience as an environmental hydrogeologist working on site characterization and remediation of contaminated properties. Mr. Long is a licensed geologist and hydrogeologist in Washington State and earned an MS in geology from the University of Wisconsin.

Trevor Louviere, EIT, Technical Professional – Engineering, will provide general engineering support under the direction of Mr. Tahghighi. He will perform engineering analyses, analyze data, develop engineering cost estimates, and prepare reports and supporting material as directed by the project manager and the senior civil engineer. Mr. Louviere has four years of experience performing field and office investigations related to contaminated site assessment and remediation. Mr. Louviere is certified as an engineer-in-training in Washington State. Mr. Louviere earned a BS in civil and environmental engineering from the University of Washington.

Charles Hand, EIT, Technical Professional – Engineering, will provide general engineering support for development and evaluation of CMS alternatives and pilot studies. He will perform engineering analyses, analyze data, develop engineering cost estimates, and prepare reports and supporting material as directed by the project manager and the senior civil engineer. Mr. Hand has three years of experience performing field and office investigations related to contaminated site assessment and remediation. Mr. Hand is certified as an engineer-in-training in Washington State and earned an MS in civil and environmental engineering from the University of Washington.

Additional junior level personnel with degrees in engineering or geology will be assigned to the project to support field work, provide routine analysis, and prepare supporting material, as needed, under the direction of the project manager, senior civil engineer, or senior hydrogeologist.

#### 10.2 Proposed CMS Schedule

The schedule proposed for completing the CMS is shown in Figure 10-2. The schedule is presented in elapsed time after formal approval of the CMS Work Plan by EPA. As shown, the first major task is completion of the pilot study to assess technology for neutralization of high pH. The results of the pilot study are needed to develop and evaluate the corrective measures alternatives. The CMS will be performed in two phases; the first phase is the pilot study and the second phase, development and evaluation of alternatives, will be performed after EPA reviews the pilot study results. Based on the assumed task durations shown in Figure 10-2, it is estimated that the CMS report would be finalized about 14 months after approval of the CMS Work Plan. It should be noted, however, that the pilot study may require additional time to complete in the field, as the kinetics for neutralizing soil are not



known. If kinetics are slower than assumed, the duration of the pilot study may be greater than shown in Figure 10-2.



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**TABLES** 



## HISTORICAL SITE USE

li i			1	Includes	<u> </u>
Location				Subsurface	Processes/Chemicals Used or
Number	Location Description	Known Releases	Existing		Historically Present
1	Former RCRA Hazardous Storage Area	No known release			Storage of methylene chloride, copper contaminated strainer solids, waste degreasing solvents, used Peneteck oil residue, vanillin still bottoms (VSB)
2	Old Meal Bin Building	No known release		х	Dry glue and resins were processed from the late 1940s through 1964. Pentachlorophenol was also handled in this building (Dames and Moore, 1986 referenced in PRC, 1990). Chemicals included dry glue, resins, soybean meal, blood meal, Zonelite, urea, soda ash, lime, pine and diesel oils, powdered tree bark, lamp black, and pentachlorophenol.
3	Main Distribution Center Building	No known release	x	х	Formerly used to manufacture glues (Landau, 1991). Casin glues, blood glues, soybean glues, tapioca flour glues, cresilic resins, urea-resorcinol formaldehyde resins, melamine formaldehyde resins, resorcinol formaldehyde resins, and melamine-urea formaldehyde resins. Chemicals associated with this manufacturing included pentachlorophenol, carbon tetrachloride, carbon disulfide, pine oil, and mineral spirits.
4	Soybean Meal Unloading	No known release			
5	Sulfuric Acid Storage	No known release			Sulfuric acid



## HISTORICAL SITE USE

I .		T		Includes	I
Location				Subsurface	Processes/Chemicals Used or
Number	Location Description	Known Releases	Existing		Historically Present
6	Cooling Tower	No known release			Area west of this area was used as a materials handling and disposal area (Landau, 1991).
7	VSP Vanillin	No known release			Former mineral oil tank was located in this area.
8	Toluene/Bisulfite Extraction	No known release, toluene release suspected based on soil data			Toluene
9	Technical Vanillin	No known release			
10	In Process Tank Storage	No known release, toluene release suspected based on soil data			Toluene
11	(b Extraction	No known release			
12	Spill Control Resevoir and Sumps	No known release			
13	Control Building	No known release			No chemical processes occurred in this area (Landau, 1991).
14	Autoclave Building	No known release		x	Housed batch reactors for vanillin production, two gas and oil-fired boilers, and copper sulfate mixing tank. Lignin, caustic, and copper sulfate (Landau, 1991).
15	Oil Storage Area	No known release			Included five above ground tanks (ASTs) and two gas and oil boilers (Landau, 1991). No. 2 fuel oil, PS 300 fuel oil, Peneteck white distilling oil, lubricating oil, antifoam agents, diesel fuel, gasoline and mineral oil.
16	In Process Tank Storage (process area)	Sulfuric acid tank solids were buried in 1969 on the east side of the area (no information about amount or depth).			Sulfuric acid tank solids
17	In Process Tank Storage	No known release			
18	Former Compressor Shed	Pydraul spill/leak area (Rhodia, 1998)			Compressor oils were used here in the past that may have contained PCBs (Landau, 1991).



## HISTORICAL SITE USE

			1	Lastrates	
Location				Includes Subsurface	Processes/Chemicals Used or
Number	Lasatian Dasanintian	Known Balanca	Fulation.		
Number	Location Description	Known Releases	Existing	Structure	Historically Present
19	Compressor Shed	No known release	Х		Used compressor oils were located here in the past that may have contained PCBs (Landau, 1991).
20	Laboratory	Compressor oil dripped and leaked onto the ground in this area between 1952 and 1980 and VBLS was disposed here once in 1979 (D&M, 1986).	X		Spent methylene chloride, compressor oil, flammable solvents, and VBLS. Aboveground storage tanks were observed to the south of the building in a 1970 air photo (Landau, 1991).
21	Former Maintenance Building (southeast)	Waste oils and solvents were disposed onto the ground here from 1952 to 1980 (D&M, 1986).			Presumably was used for storage and use of lubricating oils and cleaning solvents.
22	Spill Control/Former Containment Resevoir	No known release			
23	Spill Control Resevoir and Sumps	No known release			
24	Oil and Grease Separator	No known release			
26	Former Copper Spill Control Sump	No known release			
27	Storage and Maintenance Building	Four small mersize storage tanks were formerly located next to this building and oily residue was observed near one of these tanks.		x	Four small mersize storage tanks were formerly located next to this building. This is also the location of the former wood preservatives warehouse and steel drum storage (Landau, 1991). Chemicals used/stored included lubricating oils, parts cleaning solvents, and wood preservatives (presumably pentachlorophenol).
28	Storage Area	No known release			
29	Toluene Tanks				Stored products related to vanillin
30	Former Mud Tank for VBL				production. The VBLS (high pH)
31	Filter Press	Process waste guiacol and spent mineral oil were			was also filtered from the VBL in
32	Clarifier	disposed onto the ground in this area between 1953			this area. Chemicals included
33	Sulfite Waste Liquor Storage	and 1963. 5000 pounds of caustic soda were released near the southeast corner of the former tank	Х		SWL, sodium hydroxide, sulfuric acid, toluene, isopropyl alcohol,
34	Vanillan Black Liquor Storage	farm through an underground pipe in 1986. 98,000 pounds soil was excavated (PRC, 1990). In 1970			dioctylphthalate, copper sulfied, VBL, VBLS (high pH), used
35	Raw Material Storage	Raw Material Storage there was a sodium hydroxide overflow (unknown			phenolic-contaminated Peneteck oi
36	Caustic Storage				
37	Oil and Chemical Tanks				residues, caustic soda, mineral oil,
38	Water Tower				and guiacol.



#### HISTORICAL SITE USE

Former Rhone-Poulenc Site Tukwila, Washington

Location Number	Location Description	Known Releases	Existing	Includes Subsurface Structure	Processes/Chemicals Used or Historically Present
39	Railroad Loading/Unloading Area	No known release			
40	Guard house	No known release			
41	Adjacent to North on former Monsanto property	Monsanto reportedly disposed of precipitates on walls of vanillin reaction vessel (GeoEngineers, 1987). Chemical evidence of impacts was not substantiated in the document.			Calcium sulfate, calcium carbonate, calcium oxylate, sodium oxylate, copper.
42	Former Incinerator Location	No known release			
43	Former Roadway Between Buildings	VBL and VBLS was spread around the area for weed control between 1952 and 1965.			VBL and VBLS
44	Parking Area	Disposal of pilot plant wastes - specific location unknown.			
45	Former POW Camp Disposal Location	Most likely location used by POW encampment for waste disposal (Landau, 1991).			
Bone Yard	Boneyard Area	Plant equipment and materials were formerly stored here.			Unknown
Process Area	General Processing Area	VBL in 1976 and SWL in 1978 were discharged to the storm drainage to the Duwamish via Slip 6.  Toluene, VBL, and SWL were discharged to the Metro sewer in 1975 and 1979.  Spent mineral oil and VBL drips and leaks on the ground between 1952 and 1965.  Sulfuric acid tanks solids were buried in 1969 on the east side of the area (no information about amount or depth).			Toluene, isopropyl alcohol, sulfuric acid, mineral oil, VBL, and SWL.

Abbreviations:
(b) (4)
SWL = sulfite waste liquor VBL = vanillin black liquor VBLS = vanillin black liquor solids VSB = vanillin still bottoms



# PRELIMINARY REMEDIATION GOALS FOR SOIL

Former Rhone-Poulenc Site Tukwila, Washington

	Upland S				
	Unrestricted Industrial		Shoreline Soil		
	Use	Use, Paved	PRGs		
Constituent	(mg/kg)	(mg/kg)	(mg/kg)		
Metals					
Arsenic	20	20	14		
Cobalt	23	300			
Copper	3.55	3.55	3.55		
Lead	12.5	12.5			
Mercury	0.048	0.048	0.048		
Vanadium	390	1260	1.59		
Zinc	594	594	86		
VOCs					
Benzene	0.0127	0.0127			
Ethylbenzene	0.313	0.313			
Toluene	98.1	98.1	0.67		
Naphthalene	0.087	0.087			
SVOCs					
Pentachlorophenol	0.00684	0.00684			
Benzo(a)anthracene	0.15	21			
Benzo(a)pyrene	0.015	2.1			
Benzo[b]fluoranthene	0.15	21			
Dibenz[a,h]anthracene	0.015	2.1			
Indeno[1,2,3-cd]pyrene	0.15	21			
Pesticides					
4,4'-DDT	1.7	70			
Dieldrin	0.003	1.1			
PCBs					
PCBs, Aroclor 1254	0.22	7.4			
PCBs, Total			12 <sup>1</sup>		
TPH					
Gasoline Range Organics <sup>2</sup>	100 or 30	100 or 30			
Diesel Range Organics	2,000	2,000	200		

# Notes:

- 1. PRG is mg/kg organic carbon.
- 2. If benzene is present the lower value is the PRG.

# Abbreviations:

mg/kg = miligram per kilogram PCB = polychlorinated biphenyl

PRG = preliminary remediation goals



# PRELIMINARY REMEDIATION GOALS FOR GROUNDWATER

Former Rhone-Poulenc Site Tukwila, Washington

	Groundw	ater PRGs
Constituent	Potable Groundwater (μg/L)	Protection of Surface Water (µg/L)
Metals		
Aluminum	87	87
Arsenic	8.0	8.0
Cadmium	0.25	0.25
Chromium (total)	100	100
Copper	8.0	8.0
Lead	2.5	2.5
Mercury	0.01	0.01
Nickel	8.2	8.2
Vanadium	63	63
Zinc	56	56
VOCs		
Benzene	2.02	2.02
Ethylbenzene	700	1.71
Toluene	1,000	1,280
Naphthalene	0.14	25.6
SVOCs	_	_
Pentachlorophenol	0.00344	0.00344

# Abbreviations:

 $\mu$ g/L = micrograms per liter

PRGs = preliminary remediation goals



## SEDIMENT PRELIMINARY REMEDIATION GOALS

Former Rhone-Poulenc Site Tukwila, Washington

Sediment Depth	Arsenic (mg/kg dw)	Benzyl Alcohol (µg/kg dw)	Total PCBs
0 - 10 cm	7	57	2 ug/kg dw
10 - 45 cm	7	57	12 mg/kg OC <sup>(1)</sup>
10 - 45 CIII	7	57	500 μg/kg dw <sup>(1),(2)</sup>

#### Notes:

- 1. For the 10 to 45 centimeter (cm) depth range, either 12 mg/kg OC or 500 µg/kg dw is used, whichever is lower; for organic carbon content of less than 4.16%, 500 μg/kg dw will be lower.
- 2. Preliminary remediation goal based on clamming in the intertidal zone.

#### Abbreviations:

μg/kg dw = micrograms per kilogram on a dry weight basis cm = centimeter

mg/kg dw = miligrams per kilogram on a dry weight basis

OC = PCB concentration normalized on basis of percent organic carbon in sediment



#### **SEDIMENT REMEDIAL ACTION LEVELS**

Former Rhone-Poulenc Site Tukwila, Washington

	Remedial Action Levels	
Contaminants of Concern	(mg/kg dw)	
Arsenic	28 mg/kg dw	
Benzyl Alcohol	57 mg/kg dw	
Total PCBs	12 mg/kg OC <sup>(1)</sup>	
Total FCBS	500 μg/kg dw <sup>(1),(2)</sup>	

#### Notes:

- 1. For the 10 to 45 centimeter depth range, either 12 mg/kg OC or 500 µg/kg dw is used, whichever is lower; for organic carbon content of less than 4.16%, 500 µg/kg dw will be lower.
- 2. mg/kg normalized to organic carbon

# Abbreviations:

μg/kg dw = micrograms per kilogram on a dry weight basis mg/kg dw = miligrams per kilogram on a dry weight basis



# TABLE 6-1

# SUMMARY OF REMEDIATION TECHNOLOGIES RETAINED AFTER PRELIMINARY SCREENING

Potentially Applicable Sediment Technologies			
General Response Actions	Remediation Technologies		
Physical Removal	Dredging		
Physical Containment	Isolation/Reactive Capping		
National Decreases	Enhanced Natural Recovery		
Natural Recovery	Monitored Natural Recovery		

Potentially Applicable Soil Technologies			
General Response Actions	Remediation Technologies		
Dhysical Containment	Cap/Surface Cover		
Physical Containment	Solidification/Stabilization		
Excavation and Disposal	Excavation and Off-Site Disposal		

Potentially Applicable Groundwater Technologies			
General Response Actions	Remediation Technologies		
	Monitored Natural Attenuation		
In situ Biological Treatment	Aerobic Biodegradation		
	Bio-Mediated Stabilization		
	Chemical Oxidation		
In situ Physical/Chemical Treatment	Passive/Reactive Treatment Walls		
	In situ Acid Injection		
Mass Recovery	Pump and Treat		
Physical Containment	Landfill Caps		
Physical Containment	Barrier Wall		



## SUMMARY OF SOIL REMEDIATION TECHNOLOGIES CONSIDERED

			Technology Characteristic	cs		
General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Contaminants Addressed
<i>In Situ</i> Biological Treatment	Enhanced Bioremediation	6.2.1.1	The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance <i>in situ</i> biological degradation of organic contaminants. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials.	Full-Scale	Anaerobic bioremediation has been moderately effective on halogenated VOCs. Aerobic bioremediation has been moderately effective for SVOCs and effective for TPH. Ineffective on inorganics and PCBs.	VOCs, SVOCs, TPH
	Phytoremediation	6.2.1.2	Contaminant remediation routes include storing the contaminants in the roots, stems, or leaves of the plant, converting the contaminants into less harmful chemicals (typically in the root zone of the plant), converting the contaminants into vapors that are released to the air, or through sorbtion of the contaminants onto the plant's roots.	Full-Scale	Technology may be effective for shallow soils and for sites and soil conditions that promote plant growth.	Metals and VOCs
	Soil Vapor Extraction	6.2.1.3	Removes volatile constituents from the vadose zone. Using a blower, a vacuum is applied to wells screened in the vadose zone, and the volatiles are entrained in the extracted air and removed with the soil vapor. Off gases are generally treated to control emissions using thermal destruction or adsorption technologies.	Full-Scale	Proven reliable and effective technology for VOCs. Not effective for SVOCs, PCBs, and inorganics.	VOCs
	Bioventing	6.2.1.4	Oxygen is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.	Full-Scale	Performs well for nonhalogenated organic compounds in moist soils that biodegrade aerobically. Low effectiveness for halogenated organics. Ineffective on PCBs, inorganics, and in dry soils.	TPH, VOCs, SVOCs



## SUMMARY OF SOIL REMEDIATION TECHNOLOGIES CONSIDERED

			Technology Characteristic	cs		
General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Contaminants Addressed
In Situ Physical/Chemical Treatment	Soil Flushing	6.2.1.5	Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the groundwater to raise the water table into the contaminated soil zone. Contaminants are leached into the groundwater, which is then extracted and treated.	Full-Scale	Poor performance record. Few sites have been successfully remediated using this technology.	VOCs, TPH, SVOCs, metals
<i>In Situ</i> Thermal Treatment	Thermal Remediation	6.2.1.6	Steam, electrical energy, or soil heaters are injected below the contaminated zone to heat contaminated soil. The heating enhances the release of contaminants from the soil matrix. Some VOCs and SVOCs are stripped from contaminated zone and brought to the surface through soil vapor extraction.	Full-Scale	Performance of steam injection and stripping is highly variable and site specific. Installation of soil heaters will result in uneven heating and may desiccate soils. Electrical resistive heating can only treat COCs with boiling points below 101°C.	VOCs, SVOCs
Ex Situ Biological Treatment (assumes excavation)	Biopiles and Landfarming	6.2.2.1	Excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration to support bioremediation of organic constituents in excavated soils. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.	Full-Scale	Effective for nonhalogenated VOCs and TPH. Less effective on halogenated VOCs and poor effectiveness on PCBs. Ineffective for inorganics.	VOCs, TPH, some SVOCs
Ex Situ Physical/Chemical Treatment (assumes excavation)	Solidification/ Stabilization	6.2.2.2	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	Full-Scale	Generally effective for inorganics. Mature technology with documented performance record. Poor effectiveness for organics.	Metals
Ex Situ Thermal Treatment (assumes excavation)	Thermal Desorption	6.2.2.3	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.	Full-Scale	Proven effective at low temperature for TPH and VOCs; at high temperature, effective for SVOCs and PCBs. Proven and commercial off-the-shelf technology offered by multiple vendors. Not effective for inorganics.	VOCs, SVOCs, TPH



#### SUMMARY OF SOIL REMEDIATION TECHNOLOGIES CONSIDERED

Former Rhone-Poulenc Site Tukwila, Washington

			Technology Characteristi	cs		
General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Contaminants Addressed
Containment	Cap/Surface Cover		Surface caps constructed of asphalt concrete, Portland cement concrete, or flexible membrane liners prevent direct exposure to soil contaminants, control erosion, and reduce infiltration of stormwater into the subsurface, reducing the leaching of COCs to groundwater.	Full-Scale	Proven effective for preventing surface exposure to buried waste and for reducing infiltration of surface water through waste, limiting leaching of COCs to groundwater.	VOCs, SVOCs, TPH, metals
	Solidification/ Stabilization		Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	Full-Scale	Several different field methods are used for this generalized approach. Stabilization reagents can be effective. Complete mixing can be difficult.	Metals and higher molecular weight organics (SVOCs)
Excavation/Disposal	Off-Site Landfill Disposal		Wastes exceeding site remedial goals are excavated and transported off site to an appropriate hazardous waste land disposal facility.	Full-Scale	Proven effective for all site COCs.	VOCs, SVOCs, TPH, Metals

# Abbreviations

°C = degrees Celsius

COCs = contaminants of concern

PCBs = polychlorinated biphenyls

SVOCs = semivolatile organic compounds

TPH = total petroleum hydrocarbons

VOCs = volatile organic compounds



## SOIL REMEDIATION TECHNOLOGY SCREENING RESULTS

Soil Remediation Categories	Remediation Technologies	Section	Site-Specific Issues Affecting Technology or Implementation	Rationale for Retention or Rejection	Screening Result
<i>In Situ</i> Biological Treatment	Enhanced Bioremediation	6.2.1.1		Only moderately effective on SVOCs.     Likely ineffective on inorganics and PCBs.     Very long treatment time will likely be required.     Very high cost to implement compared to other technologies.	Reject
	Phytoremediation	6.2.1.2	<ul> <li>In situ phytoremediation is only moderately effective at remediating VOCs (TPH and SVOCs) and inorganics such as metals.</li> <li>Phytoremediation would require planting several plants across the site that would disrupt site uses.</li> <li>Remediation through plant mediated processes will likely require a long period and will require regular maintenance.</li> </ul>	Effectiveness depends on several unknown parameters that vary across the site such as salinity, COC concentrations, and soil types.     Likely ineffective on inorganics and PCBs.     Very long treatment time likely.     Very high cost to implement compared to other technologies.	Reject
	Soil Vapor Extraction	6.2.1.3	ITUTURE DEDETITS OF TECHNOLOGY ARE MINIMAL	This technology already treated source area for toluene and reached asymptotic removal point.     Technology would be difficult to implement in upland soils that are tidally influenced adjacent to barrier wall.	Reject
	Bioventing	6.2.1.4	- Effectiveness of <i>in situ</i> degradation SVOCs is low Technology is ineffective on inorganics Technology would require numerous air injection locations.	Low effectiveness on high-molecular-weight organic COCs (SVOCs) and ineffective for inorganics.     Very high cost to implement compared to other technologies.	Reject
<i>In Situ</i> Physical/Chemical Treatment	Soil Flushing	6.2.1.5	- Some areas would require different flushing agents to treat all COCs (i.e., organic	1) Technology is not proven effective in full scale applications. 2) Requires extensive and complex fluids delivery system and recovered fluids treatment system. 3) Adds chemicals into the ground that may be difficult to retrieve.	Reject



## SOIL REMEDIATION TECHNOLOGY SCREENING RESULTS

Soil Remediation Categories	Remediation Technologies	Section	Site-Specific Issues Affecting Technology or Implementation	Rationale for Retention or Rejection	Screening Result
In Situ Thermal Treatment	Thermal Remediation	6.2.1.6	- Effectiveness can be hindered by underground debris and obstructions Would require extensive network of electrode distribution points to heat soil effectively Would require excessive temperatures to provide treatment of site organic COCs and may not remediate certain site areas Would require power and excessive energy to remediate site Volatization of contaminants may result in inhalation risk for workers Proximity to waterway creates heat transport to surface water risk, which will likely adversely affect ecology Requires a lot of energy to heat soil to appropriate temperatures Requires large site foot print for fired kiln.	1) Technology will not be effective at removing all COCs (i.e., metals). 2) Technology would be difficult to implement on active site with areas separated by a barrier wall. 3) Technology requires plumbing power and excessive energy. 4) Technology will likely produce hot water/vapors that may be transported off site and adversely affect neighboring waterway.	Reject
Ex Situ Biological Treatment (assumes excavation)	Biopiles and Landfarming	6.2.2.1	- Would require extensive site excavation and soil management and removal of existing concrete cover.  - Extensive shoring and supporting systems would be required for excavations near existing structures.  - Excavation near barrier wall may adversely affect wall's integrity.  - Some impacted soils would likely remain in place due to the presence of existing structures/buildings.  - Emission control measures (e.g., tenting site) would likely be required during excavation to prevent worker and environment exposure.  - Treatability tests required to assess feasibility.  - RCRA treatment permit would likely be required.	1) Ineffective on inorganics. 2) Large excavation would disrupt existing facility cover. 3) Increased worker and public exposure risk associated with excavation and treatment process. 4) Soil may still require off-site hazardous waste disposal after treatment. 5) Large site footprint required. 6) Remedy may require months/years to reduce COC levels.	Reject
Ex Situ Physical/Chemical Treatment (assumes excavation)	Solidification/ Stabilization	6.2.2.2	<ul> <li>Would require extensive site excavation and soil management and removal of existing concrete cover.</li> <li>Extensive shoring and supporting systems would be required for excavations near existing structures.</li> <li>Excavation near barrier wall may adversely effect wall's integrity.</li> <li>Some impacted soils would likely remain in place due to the presence of existing structures/buildings.</li> <li>Emission control measures (e.g., tenting site) would likely be required during excavation to prevent worker and environment exposure.</li> <li>Can result in significant increases in soil volume ("bulk up") that would likely result in off-site disposal of excess material.</li> <li>Because organic wastes would be encapsulated but not destroyed, long-term management of wastes would be required.</li> <li>RCRA treatment permit would likely be required.</li> </ul>	Ineffective on most inorganics.     Large excavation would disrupt existing facility cover.     Increased worker and public exposure risk associated with excavation and treatment process.     Soil may still require hazardous waste offsite disposal after treatment.	Reject



#### SOIL REMEDIATION TECHNOLOGY SCREENING RESULTS

Former Rhone-Poulenc Site Tukwila, Washington

Soil Remediation Categories	Remediation Technologies	Section	Site-Specific Issues Affecting Technology or Implementation	Rationale for Retention or Rejection	Screening Result
Ex Situ Thermal Treatment (assumes excavation)	Thermal Desorption	6.2.2.3	- Would require extensive site excavation and soil management and removal of existing concrete cover.  - Extensive shoring and supporting systems would be required for excavations near existing structures.  - Excavation near barrier wall may adversely effect wall's integrity.  - Some impacted soils would likely remain in place due to the presence of existing structures/buildings.  - Emission control measures (e.g., tenting site) would likely be required during excavation to prevent worker and environment exposure.	1) Ineffective on most inorganics. 2) Large excavation would disrupt existing facility cover. 3) Increased worker and public exposure risk associated with excavation and treatment process. 4) Soil may still require hazardous waste offsite disposal after treatment. 5) Requires large site footprint. 6) Requires a lot of energy.	Reject
Physical Containment/Disposal	Cap/Surface Cover	6.2.3.1	- The site is currently a patchwork of different impervious coverings Does not remove contaminants from subsurface Cap to be used in sediment area per LDWG plan.	1) Would be effective in preventing exposure of workers at the facility to contaminated soils. 2) Extends time for short or long term <i>in situ</i> treatment methods to work. 3) Compatible with existing HCIM barrier wall.	Retain
	Solidification/ Stabilization	6.2.3.2	<ul> <li>Increases in soil volume due to stabilization or solidification reagents ("bulk up" or "fluff") can be significant.</li> <li>Excess soil may require disposal as hazardous waste.</li> <li>Presence of solidified material could affect future site development by creating structural challenges for new buildings.</li> <li>Combining containment and treatment with additives would still not address all COCs (i.e., organics).</li> </ul>	Deep soil mixing with an encapsulation technology such as cement will immobilize metals but not other organics.     The addition of a stabilization agent such as granular zero-valent iron has been identified as a potential field method that would remediate organics, reduce COC contact with groundwater, and potentially immobilize metals, thereby limiting migration of COCs from the site.	Retain
	Off-Site Landfill Disposal	6.2.3.3	- Would require extensive site excavation, soil management, and removal of existing concrete cover.  - Extensive shoring and supporting systems would be required for excavations near existing structures.  - Excavation near barrier wall may adversely affect wall's integrity.  - Some impacted soils would likely remain in place due to the presence of existing structures/buildings.  - Emission control measures (e.g., tenting site) would likely be required during excavation to prevent worker and environment exposure.	1) Capable of addressing all contaminants in vadose zone soil within the CMS Area. 2) Least administratively, logistically, and technically complex ex situ remediation technology. 3) Potentially applicable to hot spots.	Retain

#### **Abbreviations**

CMS = Corrective Measures Study
COCs = contaminants of concern
HCIM = Hydraulic Control Interim Measure
LDWG = Lower Duwamish Waterway Group
PCBs = polychlorinated biphenyls

RCRA = Resource Conservation and Recovery Act SVOCs = semivolatile organic compounds TPH = total petroleum hydrocarbons VOCs = volatile organic compounds



## SUMMARY OF GROUNDWATER REMEDIATION TECHNOLOGIES CONSIDERED

			Technology Characteristics	3		
General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Contaminants Addressed
In Situ Biological Treatment	Monitored Natural Attenuation	6.3.1.1	Intrinsic attenuation of groundwater constituents via the natural processes of biodegradation (aerobic and/or anaerobic), adsorption, and dilution. This passive technology relies on natural conditions within impacted groundwater.	Full-Scale	Has been proven effective at sites with appropriate conditions.	VOCs, TPH, SVOCs, metals
	Enhanced Anaerobic Biodegradation	6.3.1.2	Nitrate or sulfate is added to the saturated zone to act as an electron acceptor in the absence of oxygen. The increased levels of electron acceptor material promotes anaerobic biological activity. Nitrate solutions or powders can be injected into the aquifer or introduced through slow release mechanisms placed in wells.	Full-Scale	Has been effectively used at TPH (toluene) sites.	Toluene
	Aerobic Biodegradation	6.3.1.3	Oxygen/air is injected into the saturated zone to increase oxygen levels and promote aerobic biological activity. Air is delivered using a compressor and vertical or horizontal injection wells. Hydrogen peroxide or ORC solutions can be injected into the aquifer or introduced through slow release mechanisms placed in wells to release oxygen.	Full-Scale	Performs well for organic compounds that biodegrade aerobically. Not effective for inorganics or SVOCs. Primarily used at petroleum-impacted sites.	VOCs, some SVOCs, TPH
	Bio-Mediated Stabilization	6.3.1.4	Compounds targeting COCs are injected into the subsurface to encourage bioremediation of VOCs and the stabilization of metals through biologically mediated processes.	Full-Scale	Has been effectively used to reduce VOC concentrations in groundwater and to immobilize metals.	some VOCs, Metals



## SUMMARY OF GROUNDWATER REMEDIATION TECHNOLOGIES CONSIDERED

			Technology Characteristics	3		
General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Contaminants Addressed
<i>In Situ</i> Physical/Chemical Treatment	In Situ Chemical Oxidation	6.3.1.5	An oxidizing chemical (permanganate, hydrogen peroxide, Fentons Reagent, Regenox) is added to the groundwater to chemically oxidize contaminants. Usually applied through injection wells or via direct-push technology.	Full-Scale	Can be effective depending on oxidant demand of native material, tightness of formation, and number of injections. Not effective for most metals.	VOCs, SVOCs, TPH
	In-Well Air Stripping	6.3.1.6	Air is injected into a double-screened well, lifting the water in the well and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. VOCs are transferred to the vapor phase and removed by vapor extraction. Groundwater in radius of influence is aerated.	Full-Scale	Mixed performance record. Some applications have been very effective, while others have been unsuccessful in attaining cleanup objectives.	VOCs, TPH
	Permeable Reactive Barriers	6.3.1.7	Contaminant concentrations in groundwater are reduced as the groundwater flows through the permeable reactive barrier containing specialty media targeting the COCs.	Full-Scale	Has been effectively used to reduce VOC concentrations in groundwater and to immobilize metals.	VOCs, some metals
	<i>In Situ</i> Acid Injection	6.3.1.8	High pH target areas in the groundwater are addressed by the injection of an acid to reduce pH within an acceptable range. Injection methods may include the injection of a liquid or a gas.	Full-Scale/Pilot Study	Has been effectively used to reduce pH in groundwater.	рН
In Situ Thermal Treatment	Thermal Remediation	6.3.1.9	Temperature in the saturated zone is increased by injecting steam or applying an electrical current. The increased temperature volatilizes organic compounds, which would be collected from the vadose zone using SVE.	Full-Scale	Mixed performance record. Some applications have been effective, while others have been unsuccessful in attaining cleanup objectives. Not effective for inorganics.	VOCs, TPH, SVOCs



## SUMMARY OF GROUNDWATER REMEDIATION TECHNOLOGIES CONSIDERED

			Technology Characteristics	3		
General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Contaminants Addressed
	Bioreactors	6.3.2	Extracted groundwater is pumped into a bioreactor where air is injected to promote aerobic biodegradation or substrate is added to promote anaerobic biodegradation	Full-Scale	Has been effectively used to remove contaminants to some extent depending on HRT.	VOCs and TPH
	Adsorption	6.3.2	This technology is used in conjunction with pump- and-treat systems. Extracted groundwater is passed through vessels containing granular activated carbon or another adsorbent media. COCs with an affinity for the media are transferred from the aqueous phase to the solid phase by sorption to the media.	Full-Scale	Has been effectively used to remove VOCs, SVOCs, TPH and some inorganics.	VOCs, SVOCs, TPH, and some inorganics
Ex Situ Groundwater Extraction and Treatment (Pump and Treat)	Advanced Oxidation Processes	6.3.2	Extracted groundwater is oxidized either through the use of chemicals added to the groundwater such as ozone, persulfate, hydrogen peroxide or through the use of ultraviolet light to destroy VOCs and some SVOCs.	Full-Scale	Has been effectively used for VOCs, TPH, and SVOCs.	VOCs, SVOCs, and TPH
	Air Stripping	6.3.2	Extracted groundwater is passed downward against a stream of rising air. The countercurrent stream of air strips VOCs from the water. Contaminants in the air stream are then removed or treated by oxidation or adsorption technologies.	Full-Scale	Has been effectively used to remove VOCs from groundwater.	VOCs
	Ion Exchange	6.3.2	Extracted groundwater is pumped through ion exchange media to remove inorganics. Inorganics are removed depending on affinity to the media, concentration, and competing ions.	Full-Scale	Effective against target inorganics.	Metals



## SUMMARY OF GROUNDWATER REMEDIATION TECHNOLOGIES CONSIDERED

Former Rhone-Poulenc Site Tukwila, Washington

			Technology Characteristics	3		
General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Contaminants Addressed
Ex Situ Groundwater Extraction and Treatment (Pump and Treat) (cont.)	Precipitation/Coagu lation/Flocculation	6.3.2	Ex situ treatment process use combination of precipitation (pH adjustment), coagulation, and flocculation to remove inorganics.	Full-Scale	May address inorganics and some SVOCs.	Metals and SVOCs
	Filtration	6.3.2	Extracted groundwater is pumped through filters or distillation units to remove metals, SVOCs, and some VOCs.	Full-Scale	Has been effectively used to treat metals and SVOCs. May be effective for some VOCs.	Metals, SVOCs, and some VOCs
	Acid Neutralization	6.3.2	An acid such as sulfuric or hydrochloric acid is added to reduce the pH of extracted groundwater.	Full-Scale	Has been effectively used to reduce pH of high pH groundwater.	High pH
Physical Containment	Impermeable Caps	6.3.3.1	Placement of a low-permeability asphalt or soil- based cap on soils overlying impacted groundwater.	Full-Scale	Has been effectively used at the site already to contain contaminated groundwater.	VOCs, SVOCs, TPH, metals
	Barrier Walls	6.3.3.2	Placement of a barrier wall that physically restricts flow of groundwater. The wall must be keyed into lower confining unit for total containment.	Full-Scale	Has been effectively used at the site already to contain contaminated groundwater.	VOCs, SVOCs, TPH, metals

## **Abbreviations**

COCs = contaminants of concern

HRT = hydraulic retention time

ORC = oxygen releasing compound

SVE = soil vapor extraction

SVOCs = semivolatile organic compounds

TPH = total petroleum hydrocarbons

VOCs = volatile organic compounds



## **GROUNDWATER REMEDIATION TECHNOLOGY SCREENING RESULTS**

General Response Actions	Remediation Technologies	Section	Site-Specific Issues Affecting Technology or Implementation	Rationale for Retention or Rejection	Screening Result
	Monitored Natural Attenuation	6.3.1.1		Natural attenuation is a viable process and has been documented to be is actively occurring at the site.     Low cost alternative compared to other treatment technologies.	Retain
	Enhanced Anaerobic Biodegradation	6.3.1.2	- Monitoring is required to confirm effectiveness.  - Does not address metals and many other organics (SVOCs)	Uncertainty in effectiveness.     May require several injections and a long restoration time frame.     Only addresses toluene.	Reject
In Situ Biological Treatment	Aerobic Biodegradation	6.3.1.3	' '	May be useful for contingency treatment if aerobically biodegradable compounds are recalcitrant.     May be used to target toluene hotspots or as a funnel and gate method.	Retain
	Bio-Mediated Stabilization	6.3.1.4		May be used to target inorganics such as metals.     May be used to target hotspots or as a funnel and gate method.	Retain
In Situ	<i>In Situ</i> Chemical Oxidation	6.3.1.5	<ul> <li>High reduced iron concentrations and organic carbon at the site would exert a large oxygen demand, affecting efficiency of treatment.</li> <li>May be difficult to obtain effective oxidant distribution in areas with silt, clay, and other subsurface obstructions.</li> <li>Would likely require pilot study for oxidant demand.</li> <li>Ineffective for inorganics.</li> </ul>	Results in permanent destruction of organics.     May be used to address hot spots or as a funnel and gate method to intercept plume.	Retain
Physical/Chemical Treatment	In-Well Air Stripping	6.3.1.6		This technology has a mixed performance record.     Technology would result in significant iron fouling.     Would require long-term operation and maintenance.     Would only address very localized areas.	Reject



#### **GROUNDWATER REMEDIATION TECHNOLOGY SCREENING RESULTS**

Former Rhone-Poulenc Site Tukwila, Washington

General Response Actions	Remediation Technologies	Section	Site-Specific Issues Affecting Technology or Implementation	Rationale for Retention or Rejection	Screening Result
In Situ	Permeable Reactive Barriers	6.3.1.7	- Would be difficult to build a passive/reactive barrier that was effective at reducing all COCs below cleanup levels Construction could interfere with activities at the facility PRB would need to consist of multiple materials to address site COCs.	May be useful in targeted locations or for contingency treatment.     May be used in a funnel and gate method to address inorganics and organics.	Retain
Physical/Chemical Treatment (cont.)	In Situ Acid Injection	6.3.1.8	<ul> <li>High concentrations of silica in the groundwater will create plugging problems with injection locations due to precipitation of the silica.</li> <li>Injections adjacent to the waterway pose an exposure risk.</li> <li>Handling hazardous materials.</li> <li>Potential for overshooting and reducing the pH too much.</li> </ul>	May be useful in targeted locations or for contingency treatment.     Only method to target deep groundwater hotspots.	Retain
<i>In Situ</i> Thermal Treatment	Thermal Remediation		- This technology would require numerous steam injection points or heating elements and an off-gas treatment system to capture the volatilized contaminants.  - The energy requirement to treat (heat) deeper groundwater has high costs.  - Technology could not be used in proximity to plastic utility lines.  - Technology would not address inorganics.	1) Technology is expensive when compared to other treatment technologies. 2) Site disturbance required to implement technology and SVE system. 3) Technology only addresses organics.	Reject
Ex Situ Groundwater Extraction and Treatment (Pump and Treat)	Groundwater Pump and Treat System	6.3.2	I- Large Site tootprint required	Technology would require long term maintenance.     Technology would take a long time to remediate site.     Large site footprint.	Retain
Physical	Impermeable Caps	6.3.3.1	- Construction of caps require large site disturbance Cap does not remove site contaminants.	Cap is a good way to reduce infiltration and COC migration.     Caps provide more time for <i>in situ</i> remediation methods.	Retain
Containment	Barrier Walls	6.3.3.2	Barrier wall already constructed at site and containing the HCIM area.     Long term maintenance required for wall.	Barrier wall already employed at site in conjunction with recovery system for containment.     Barrier wall would be maintained unless entire site excavation is performed.	Retain

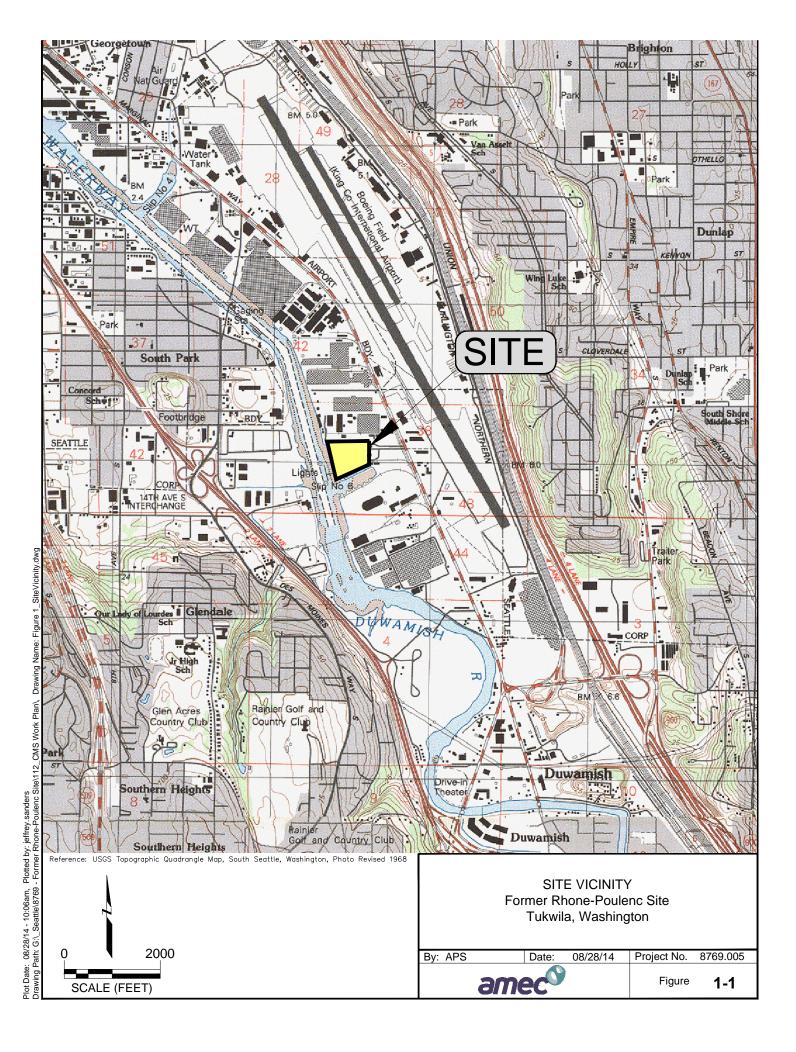
#### **Abbreviations**

COCs = contaminants of concern
HCIM = hydraulic control interim measure
PRB = permeable reactive barrier
SVE = soil vapor extraction

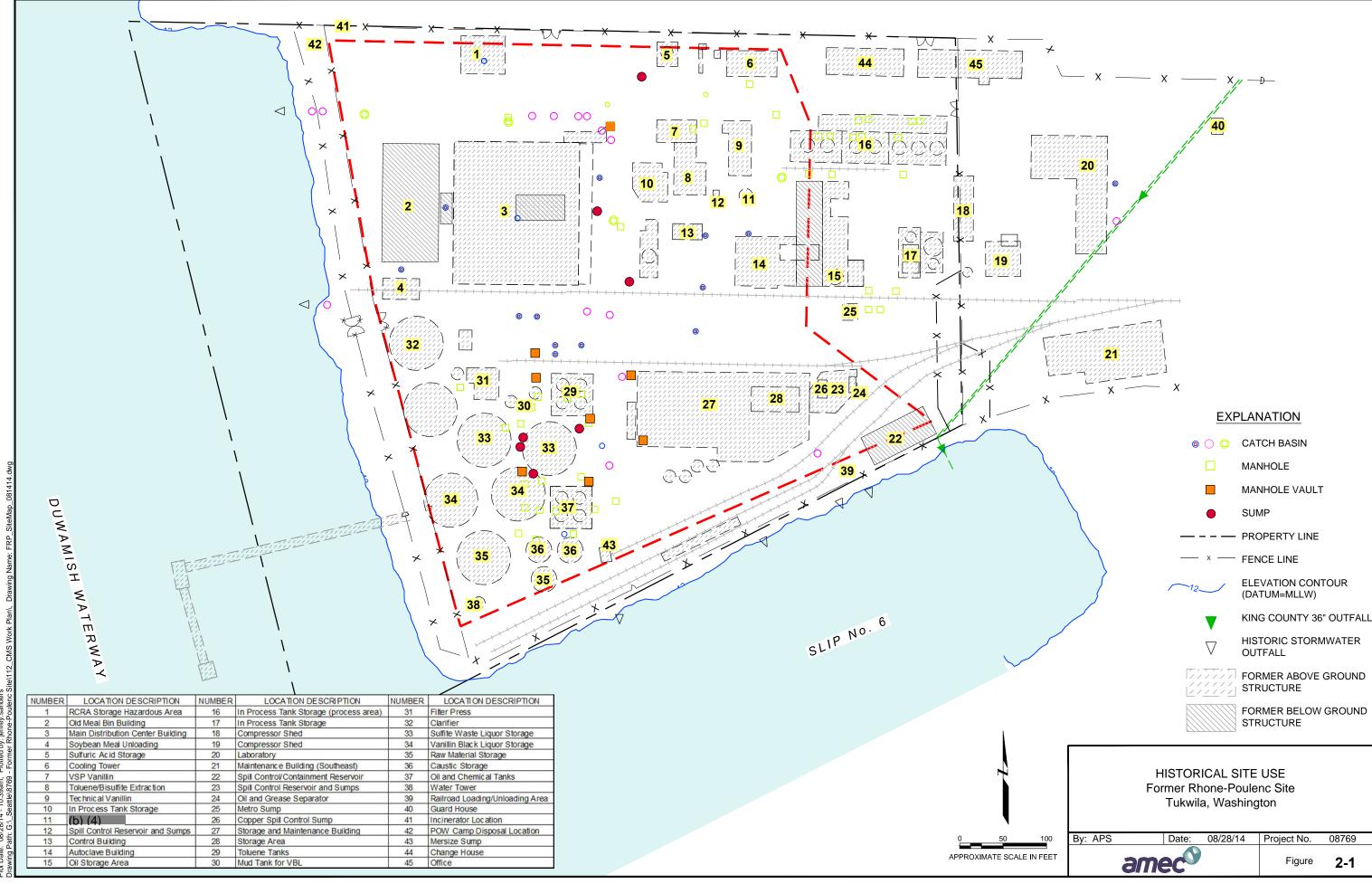
SVOCs = semivolatile organic compounds TPH = total petroleum hydrocarbons VOCs = volatile organic compounds

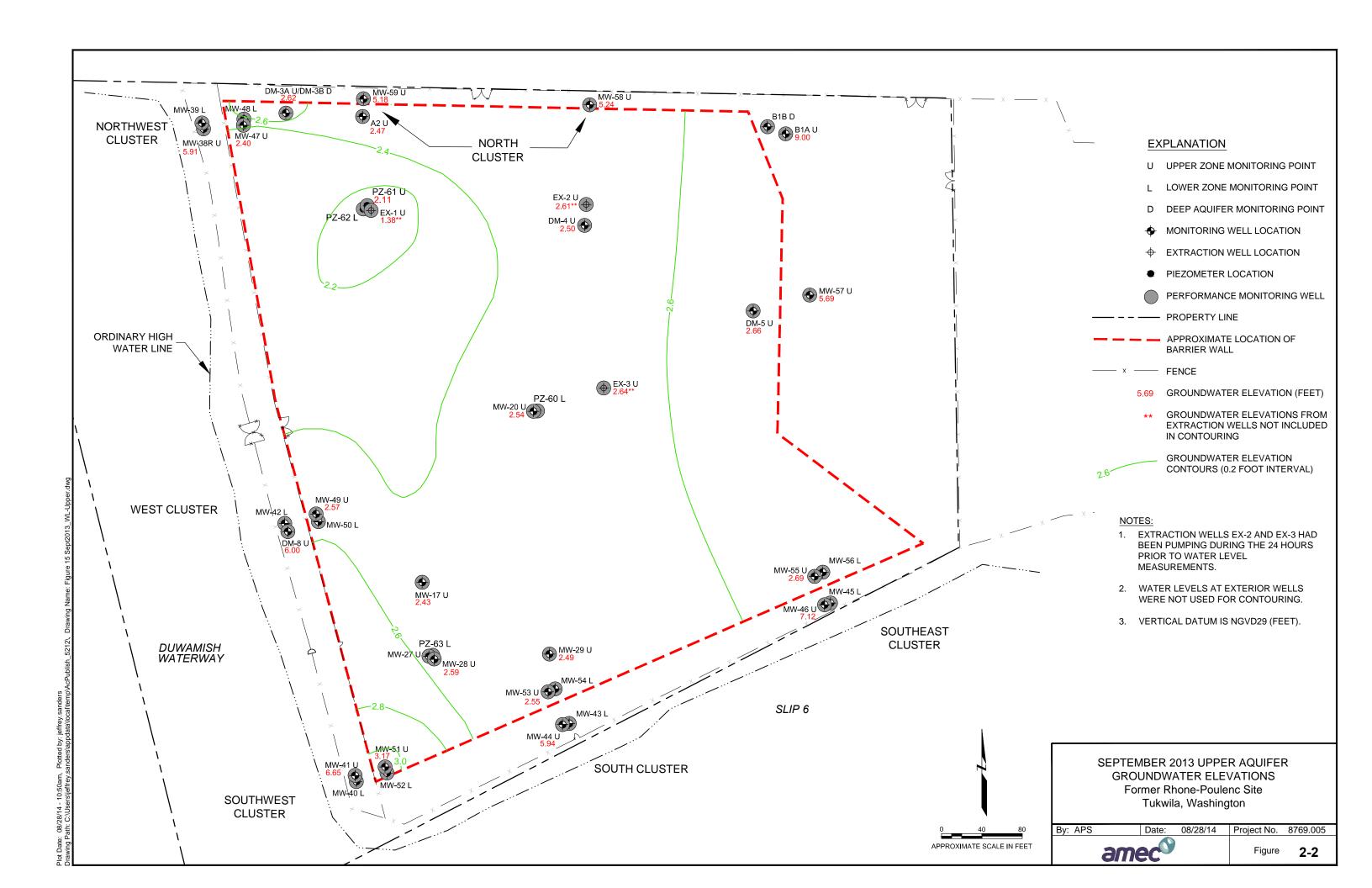


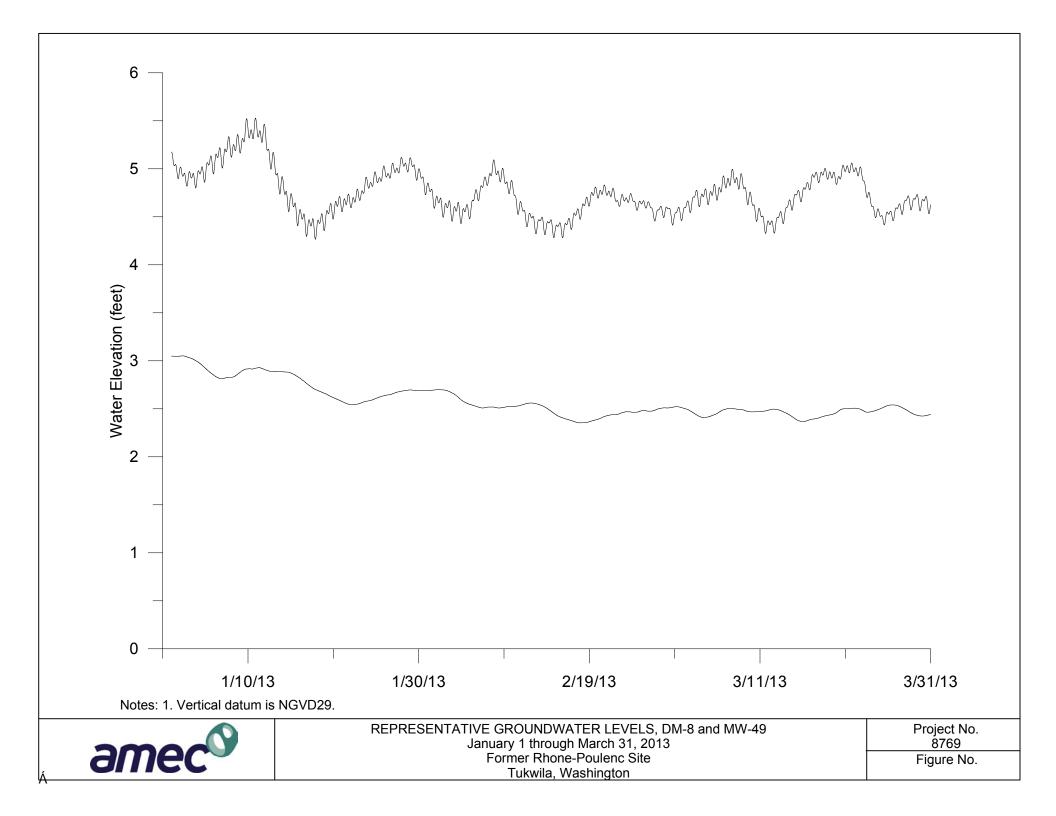
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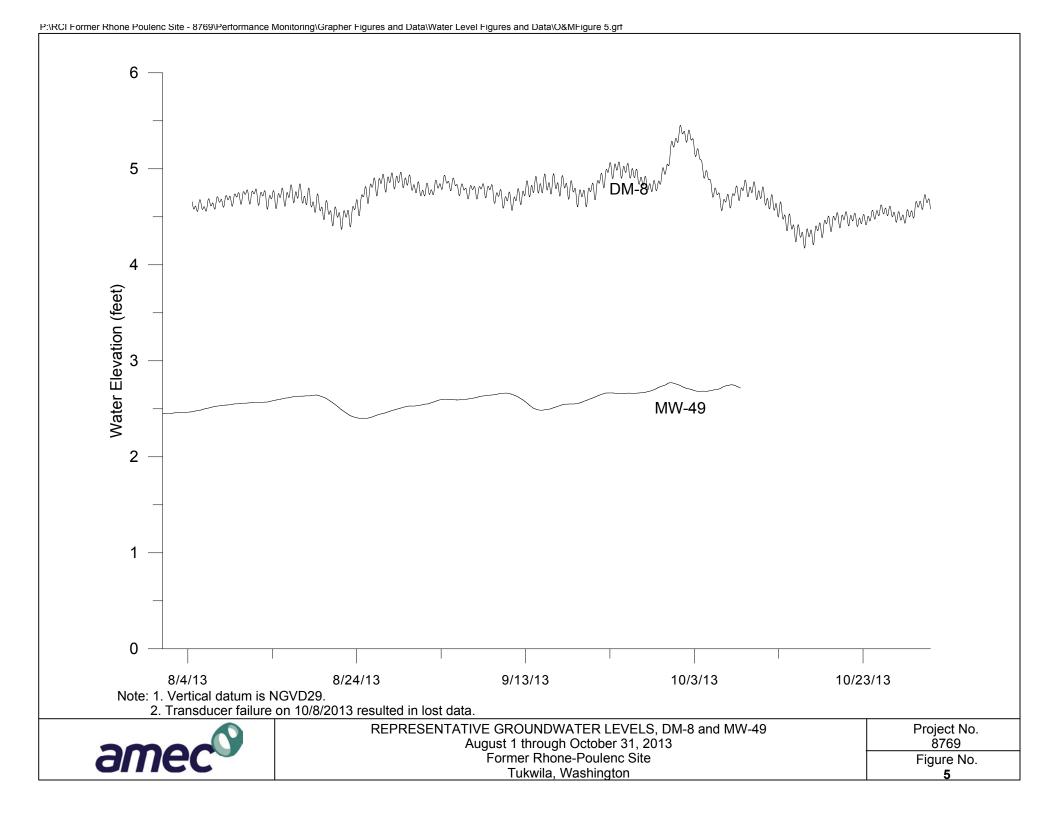


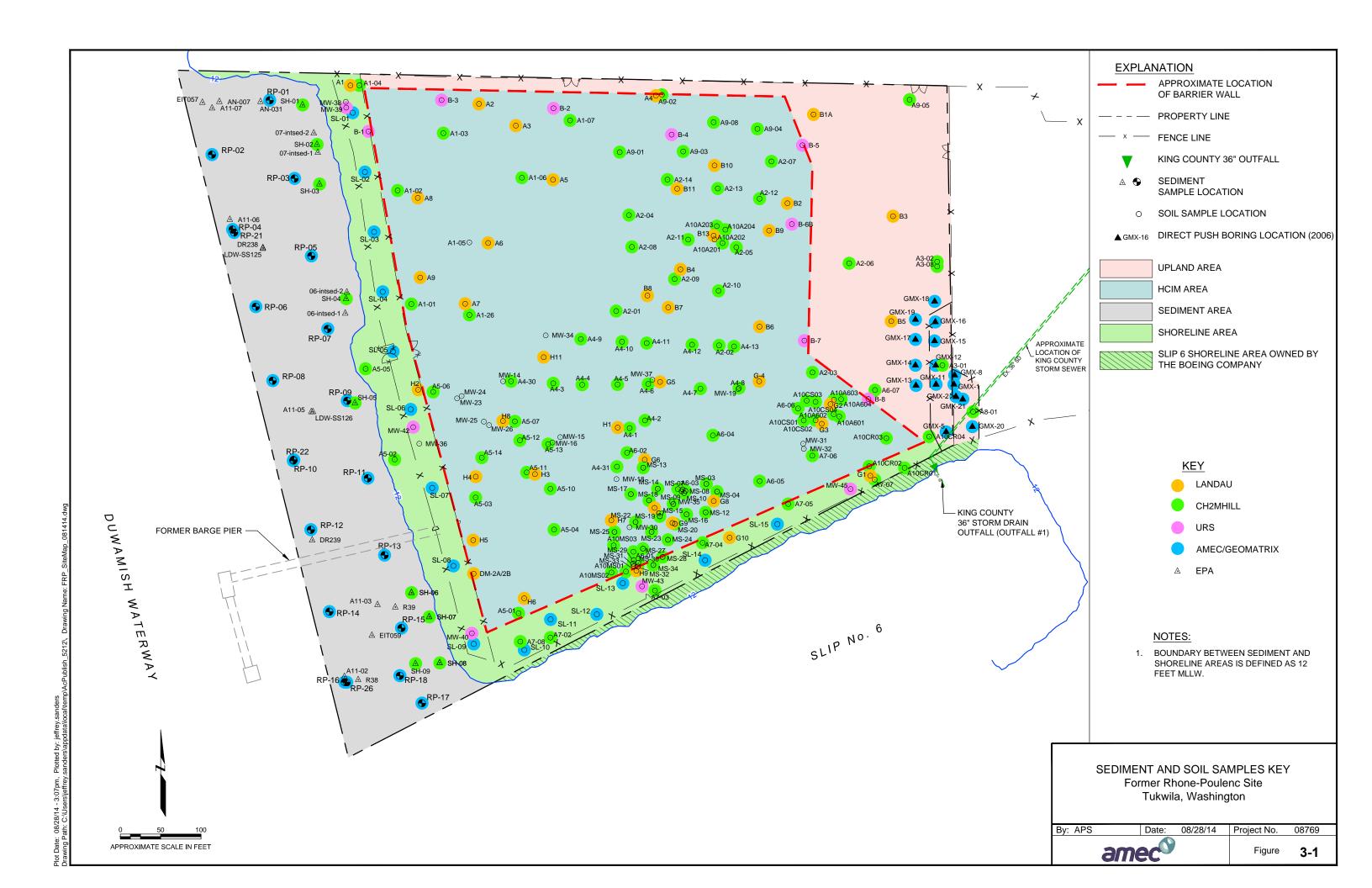


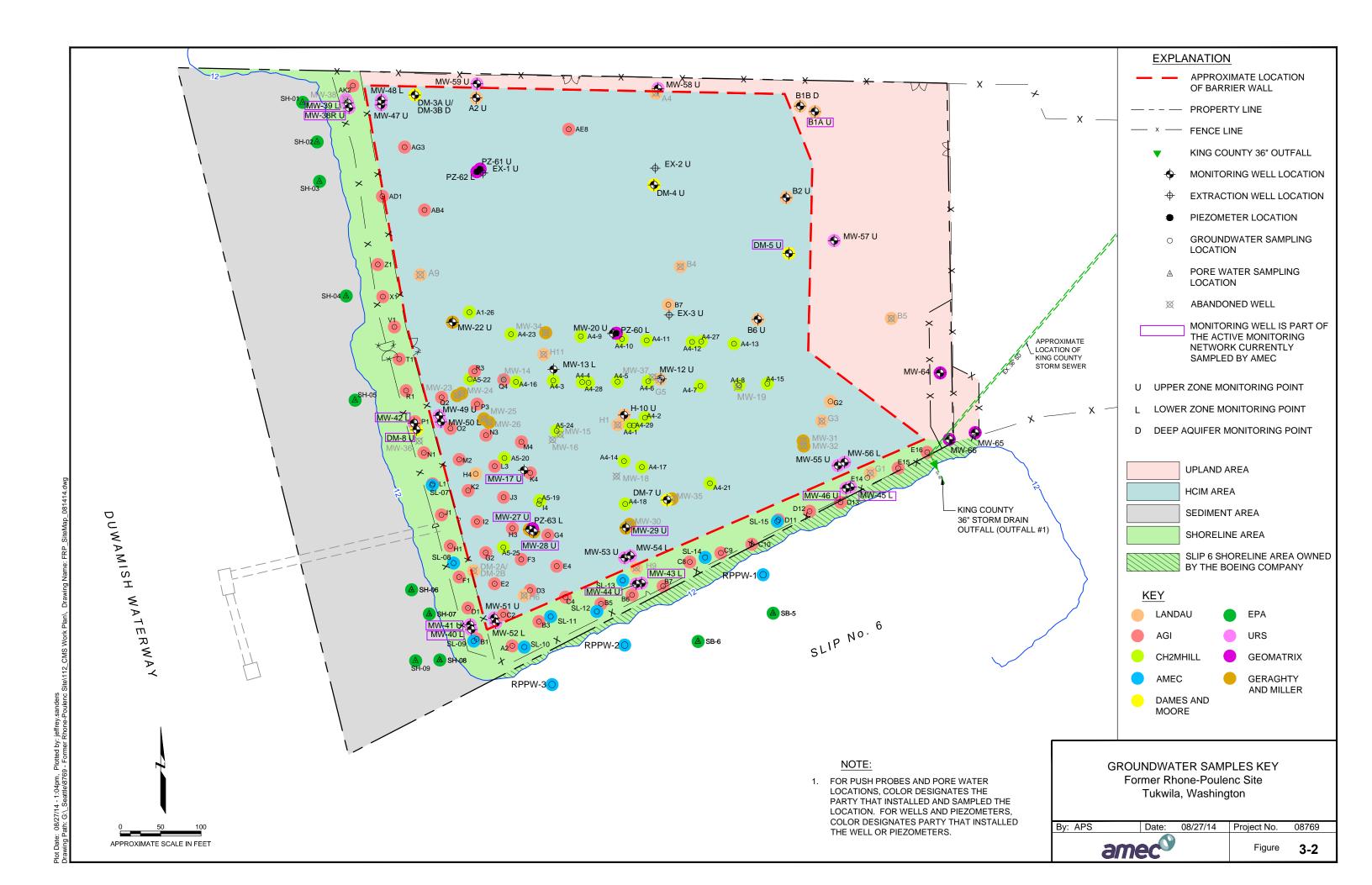


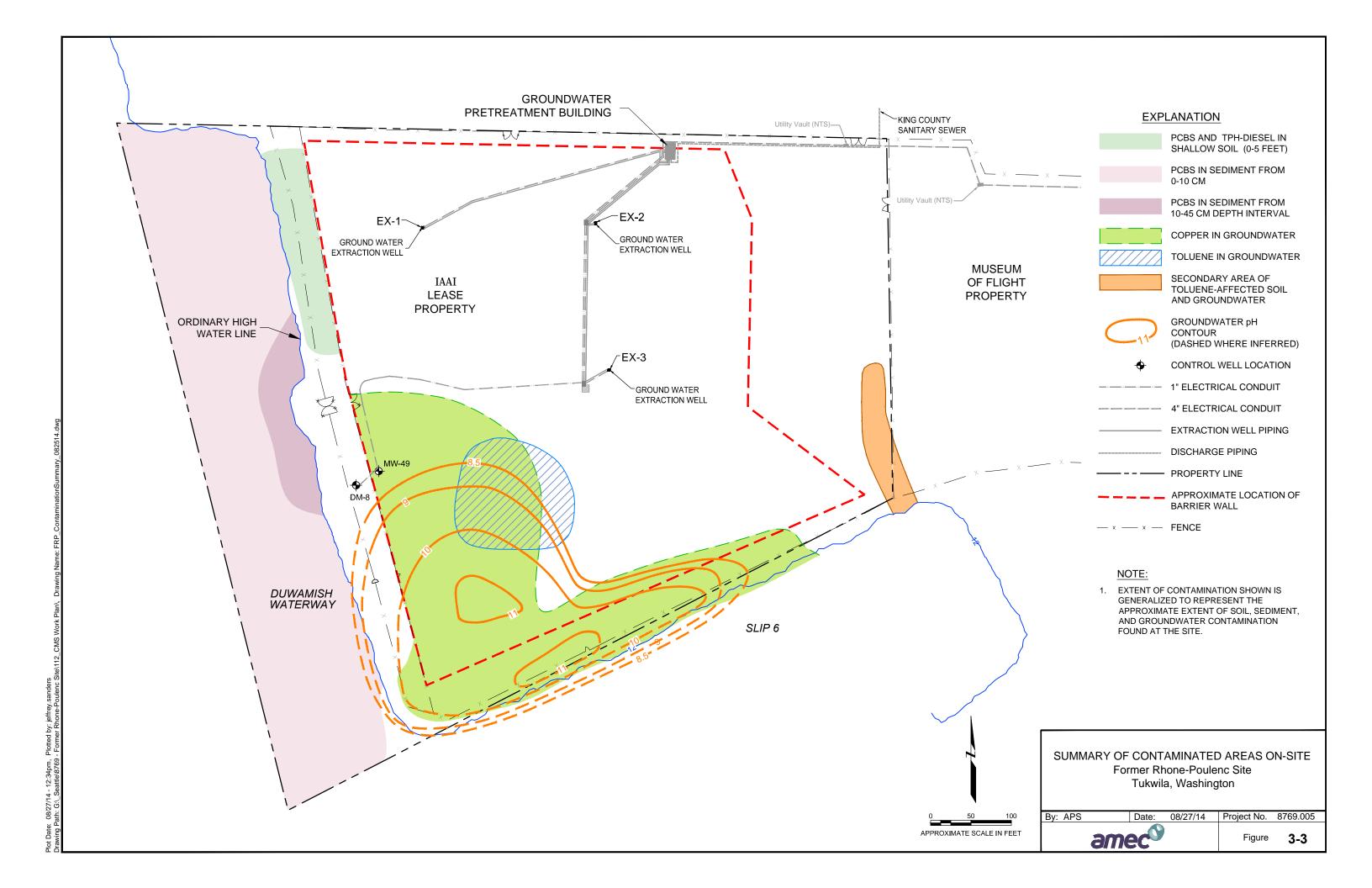


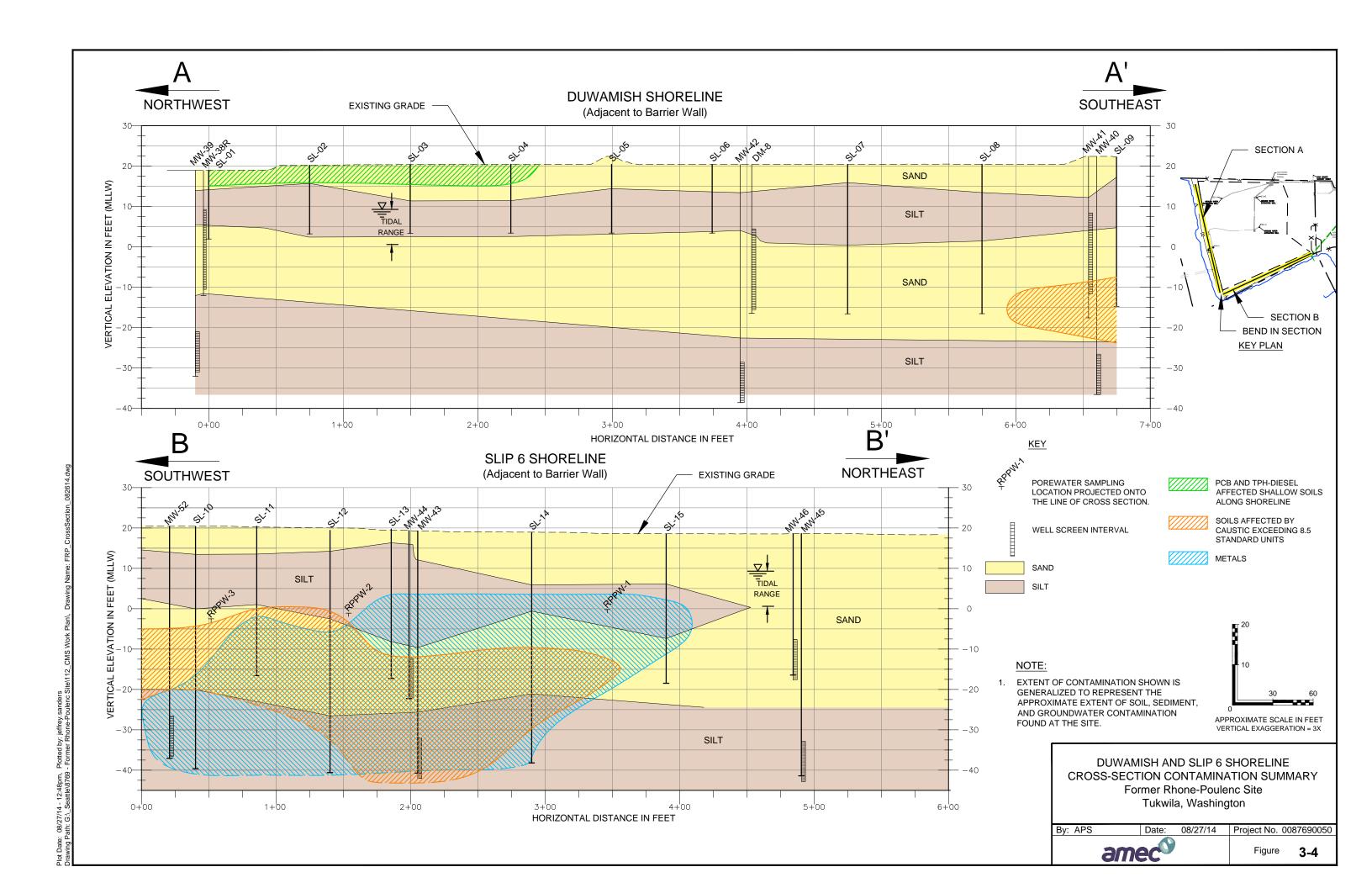


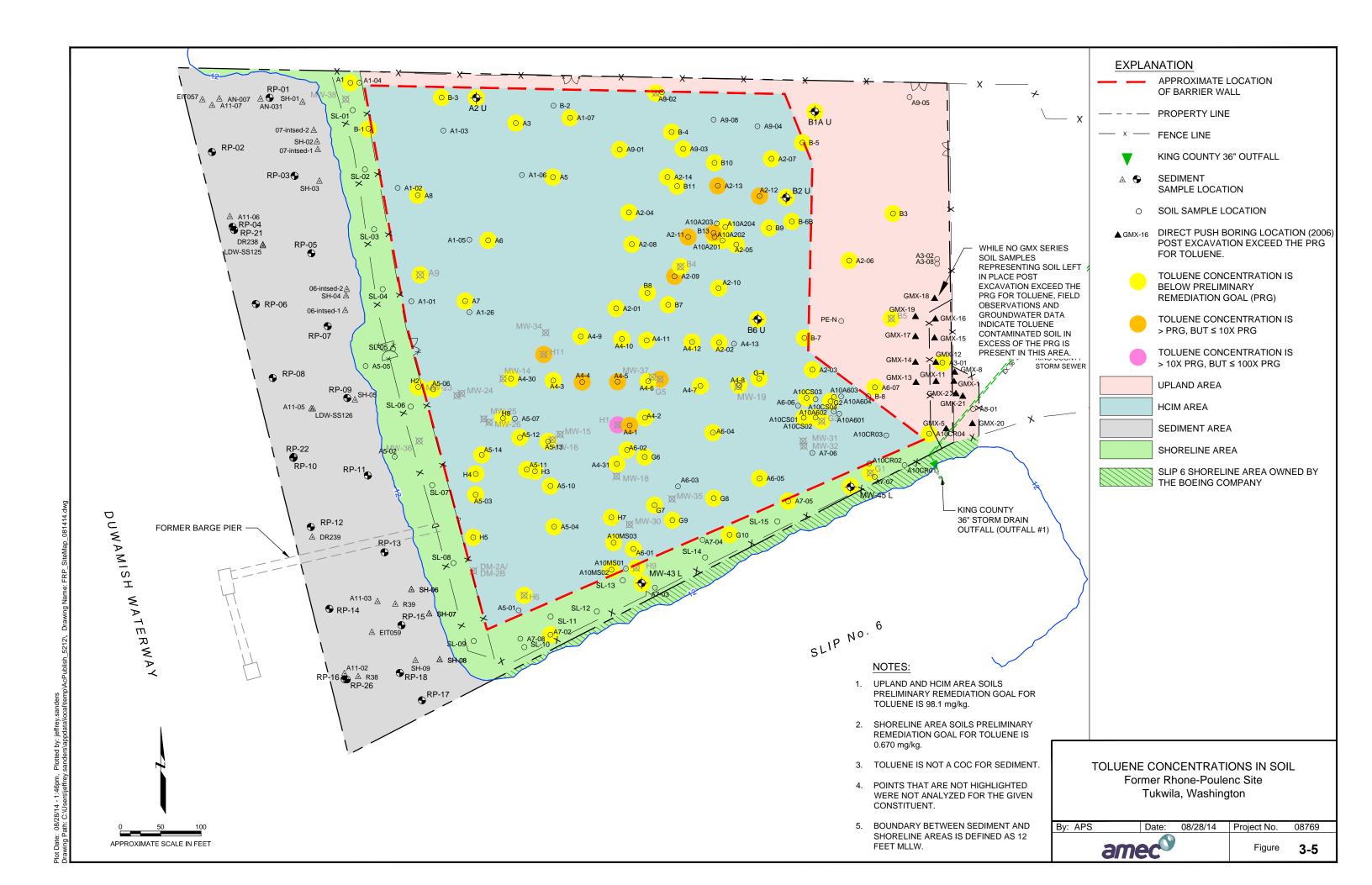


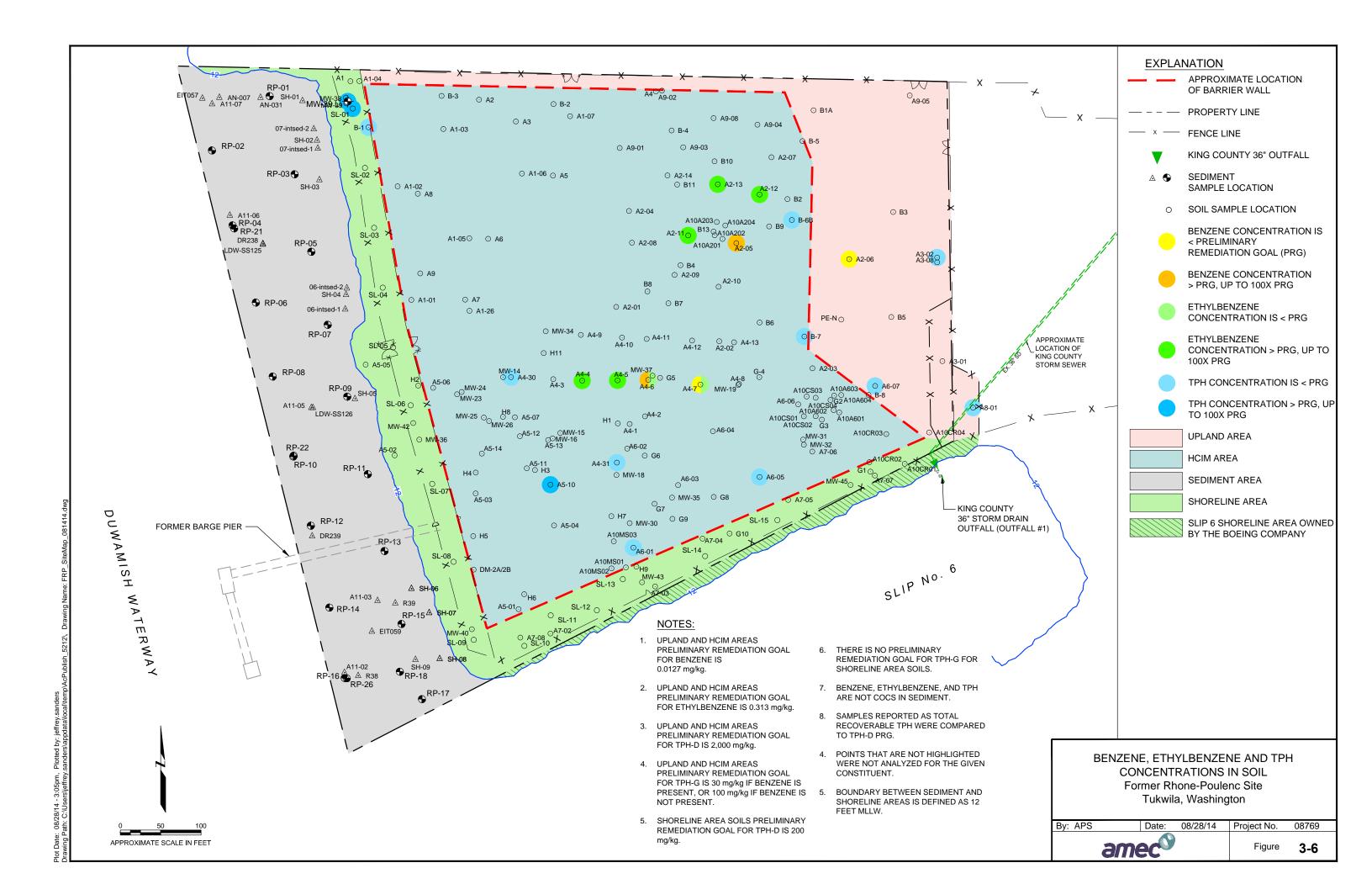


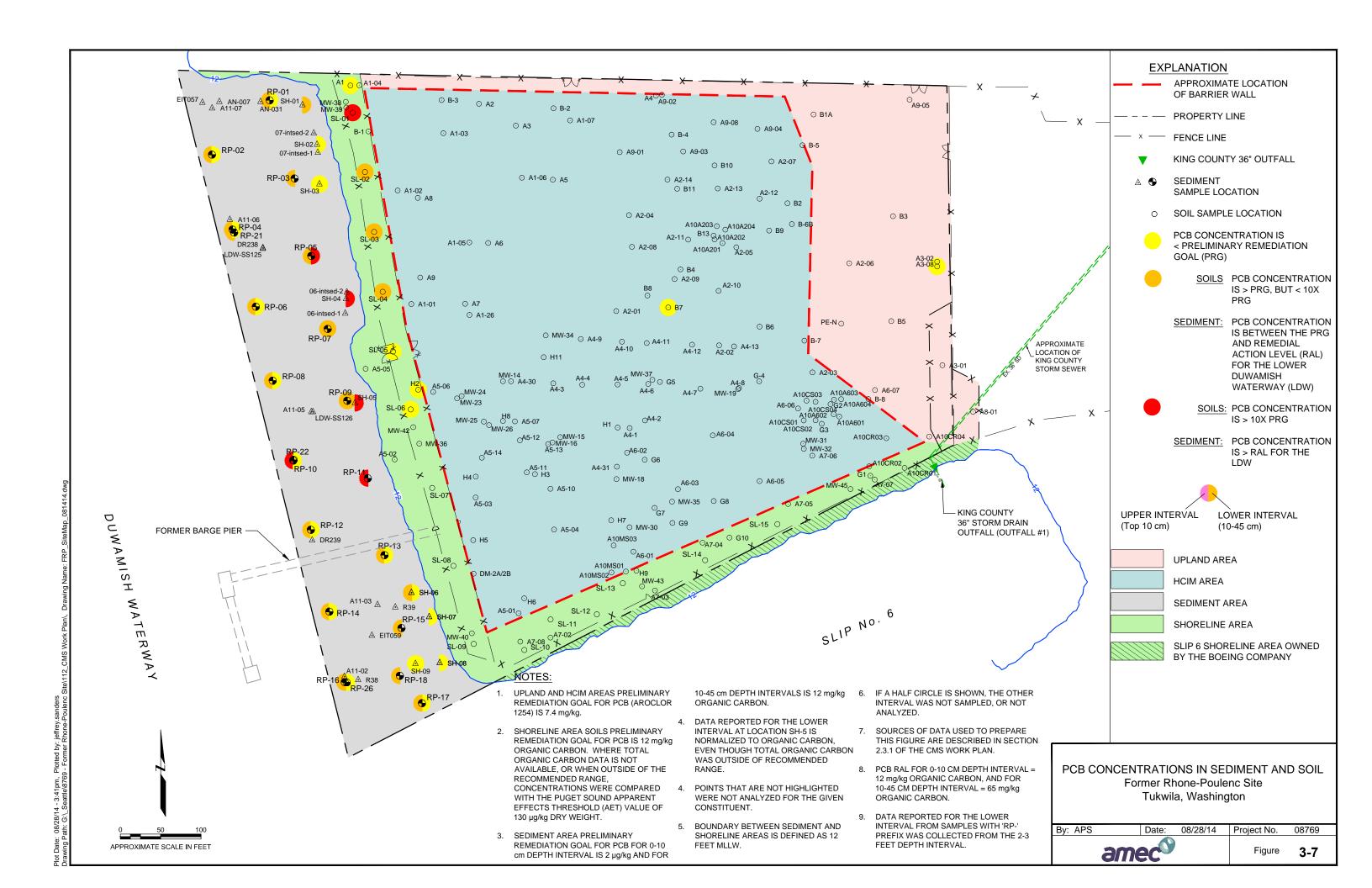


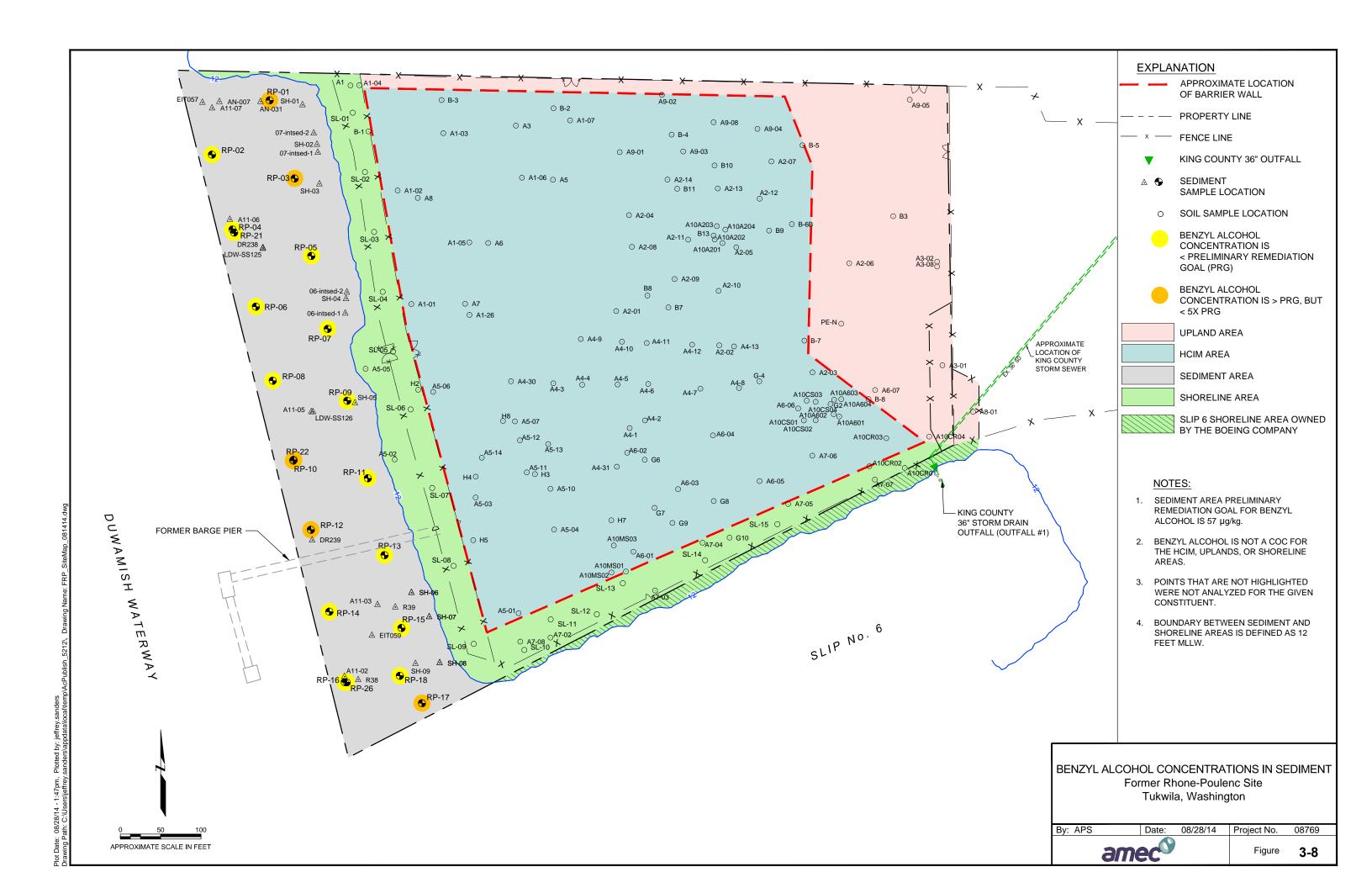


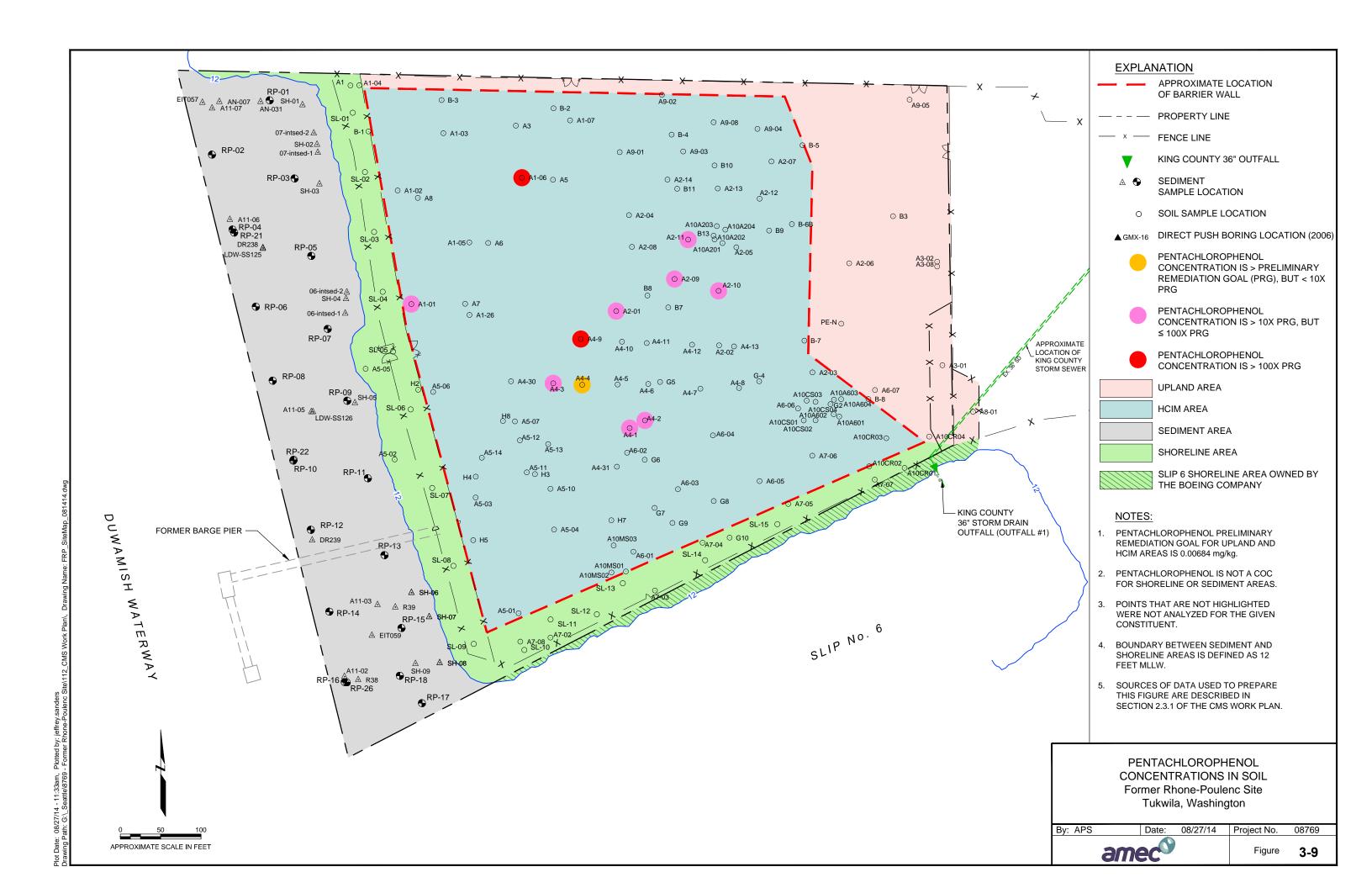


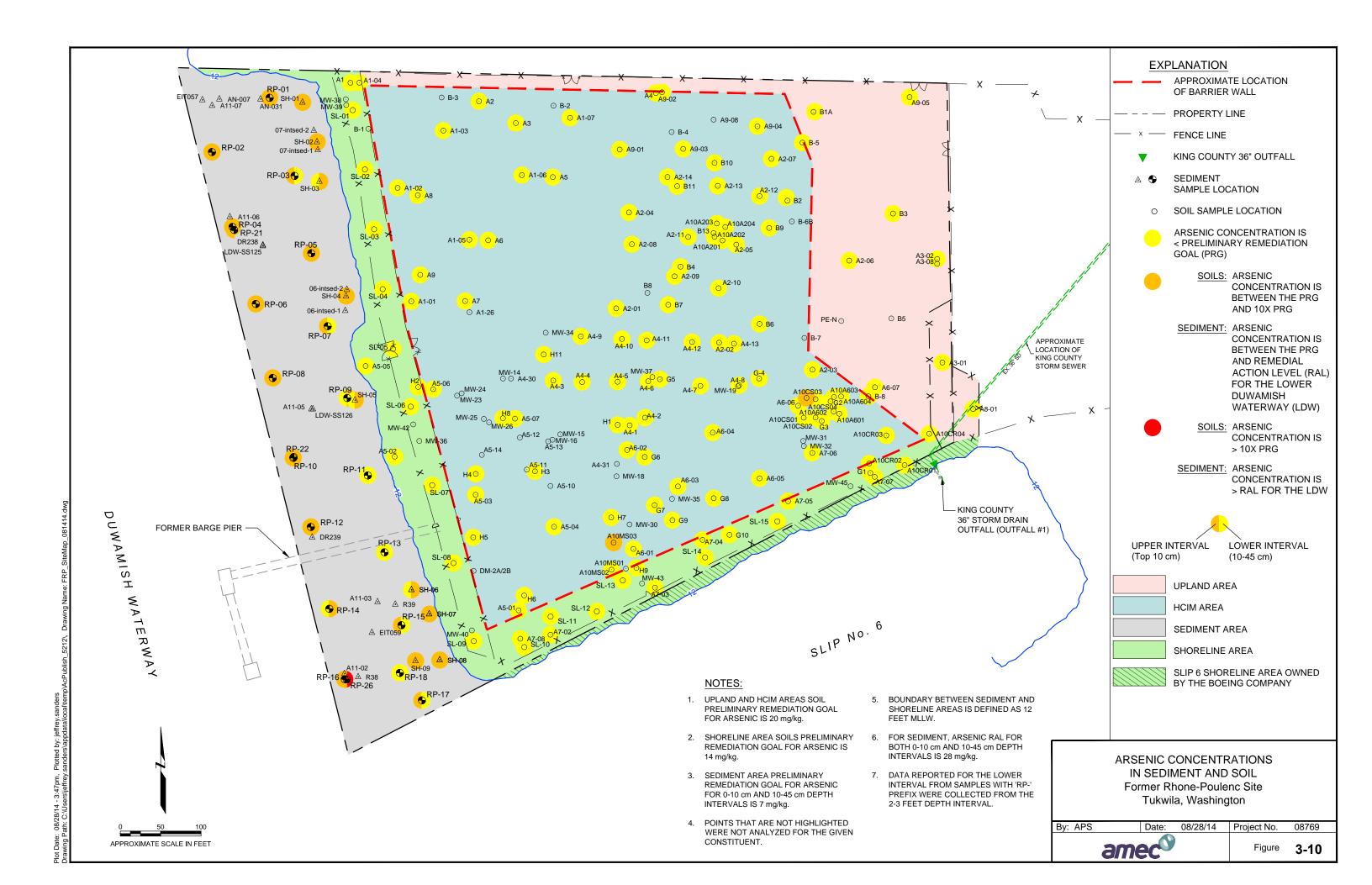


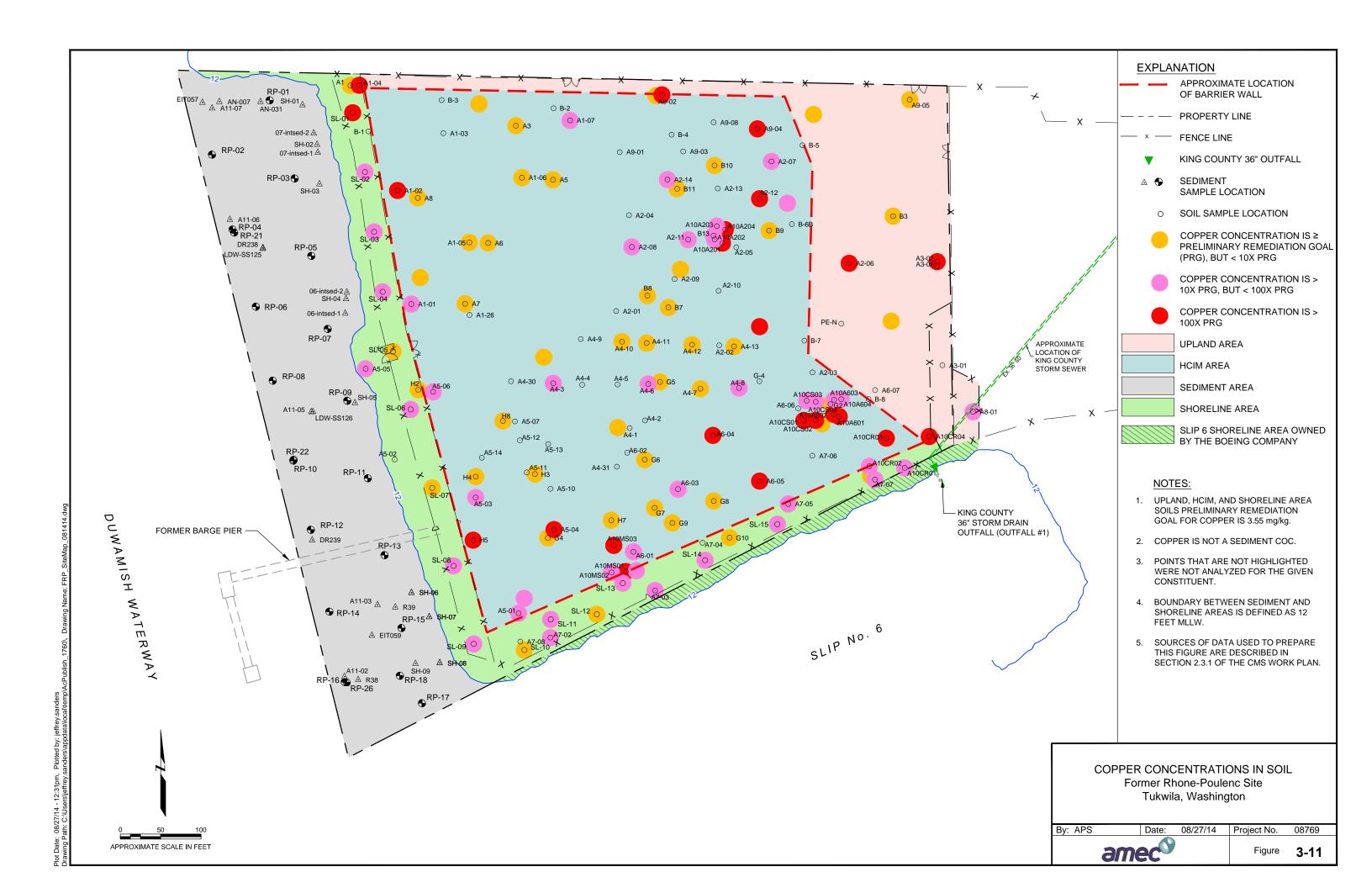


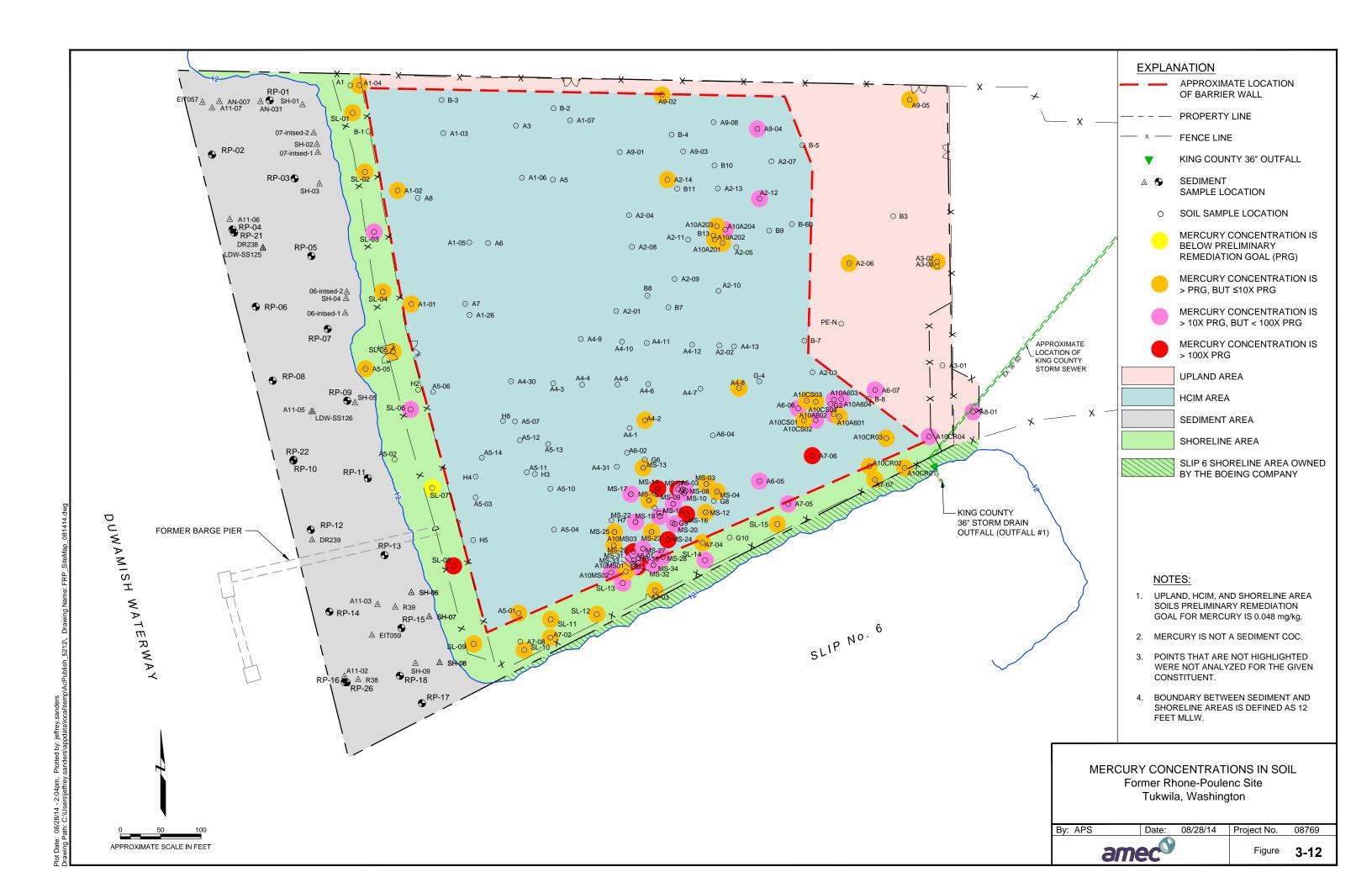


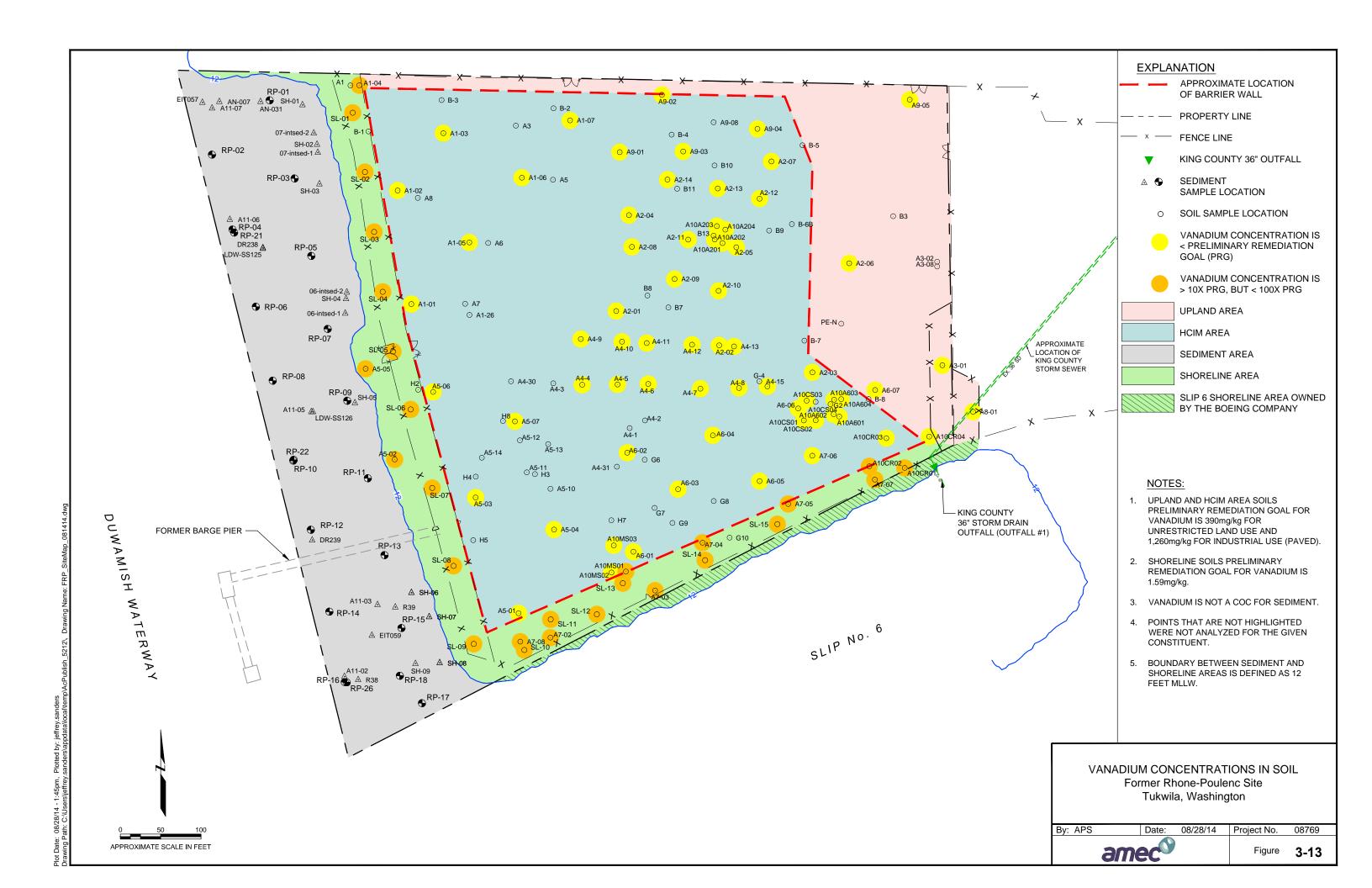


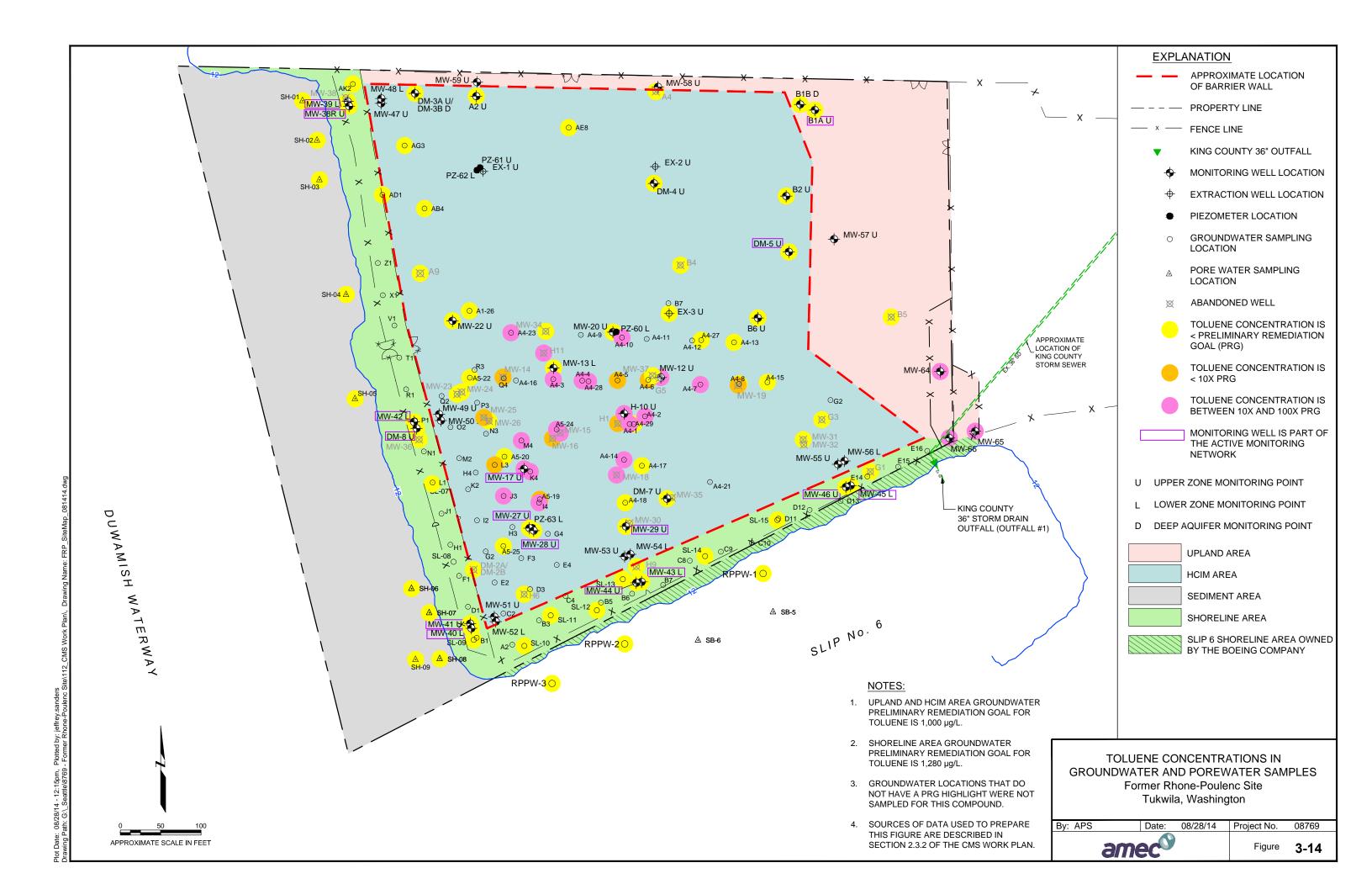


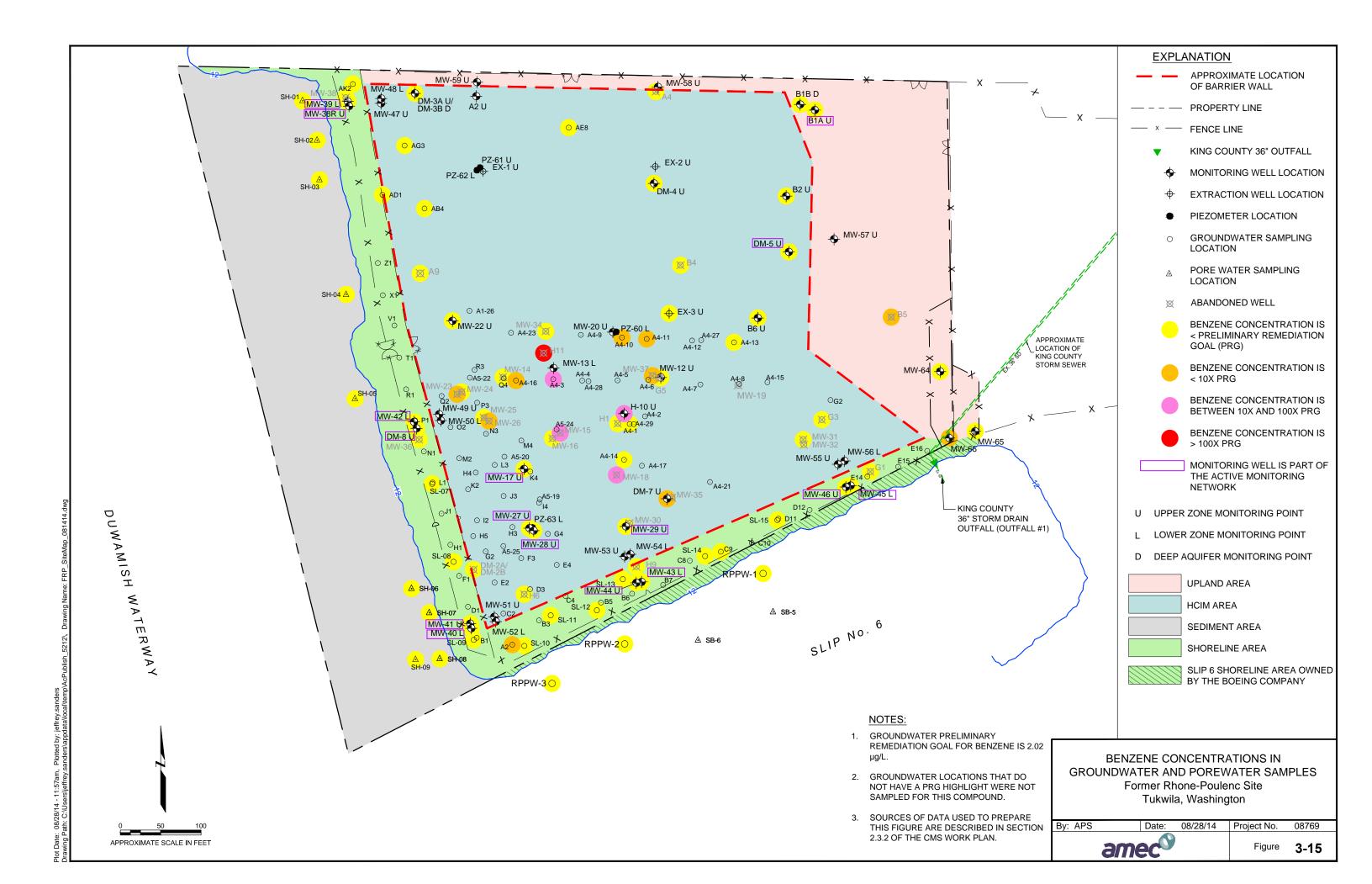


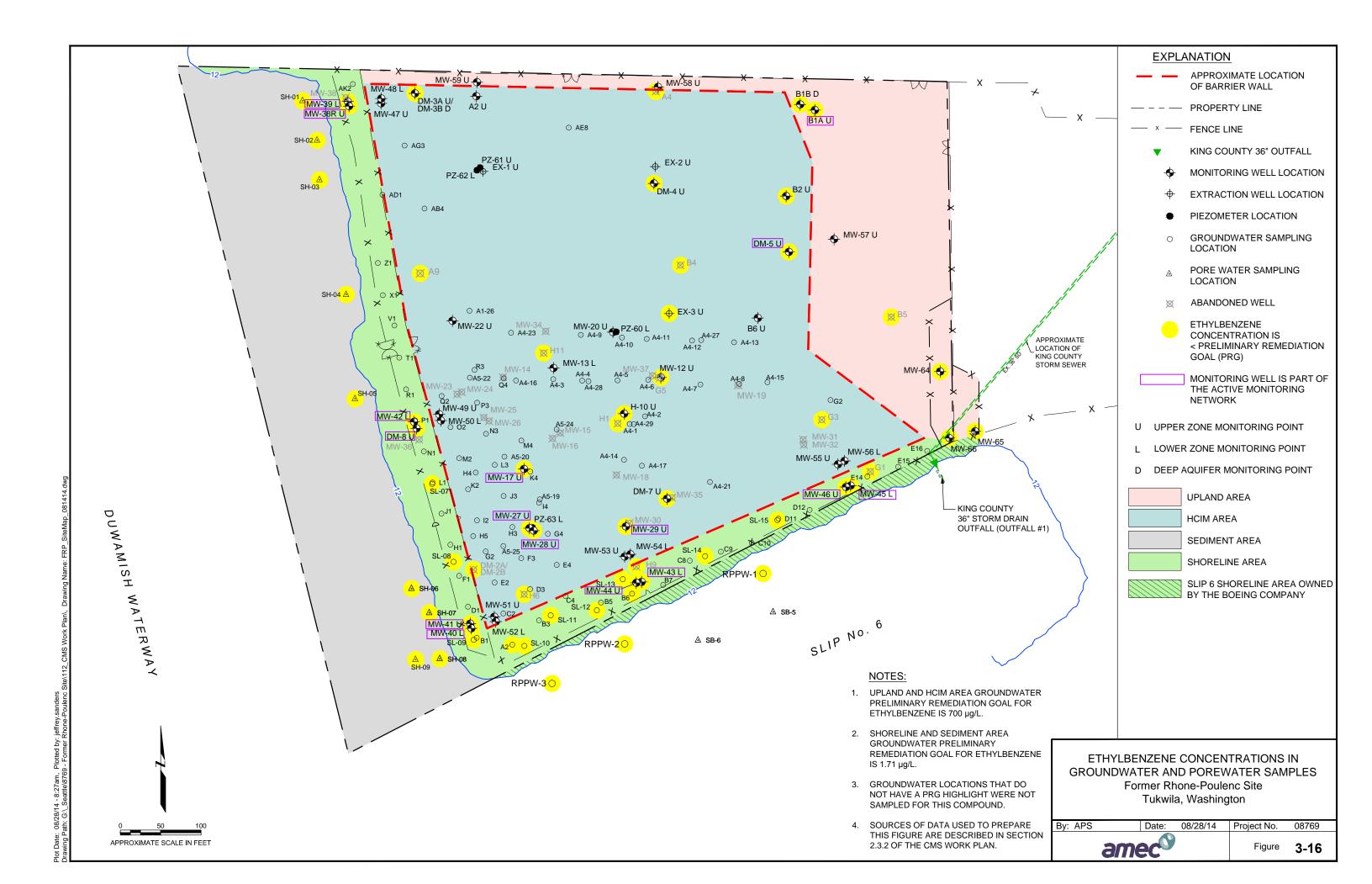


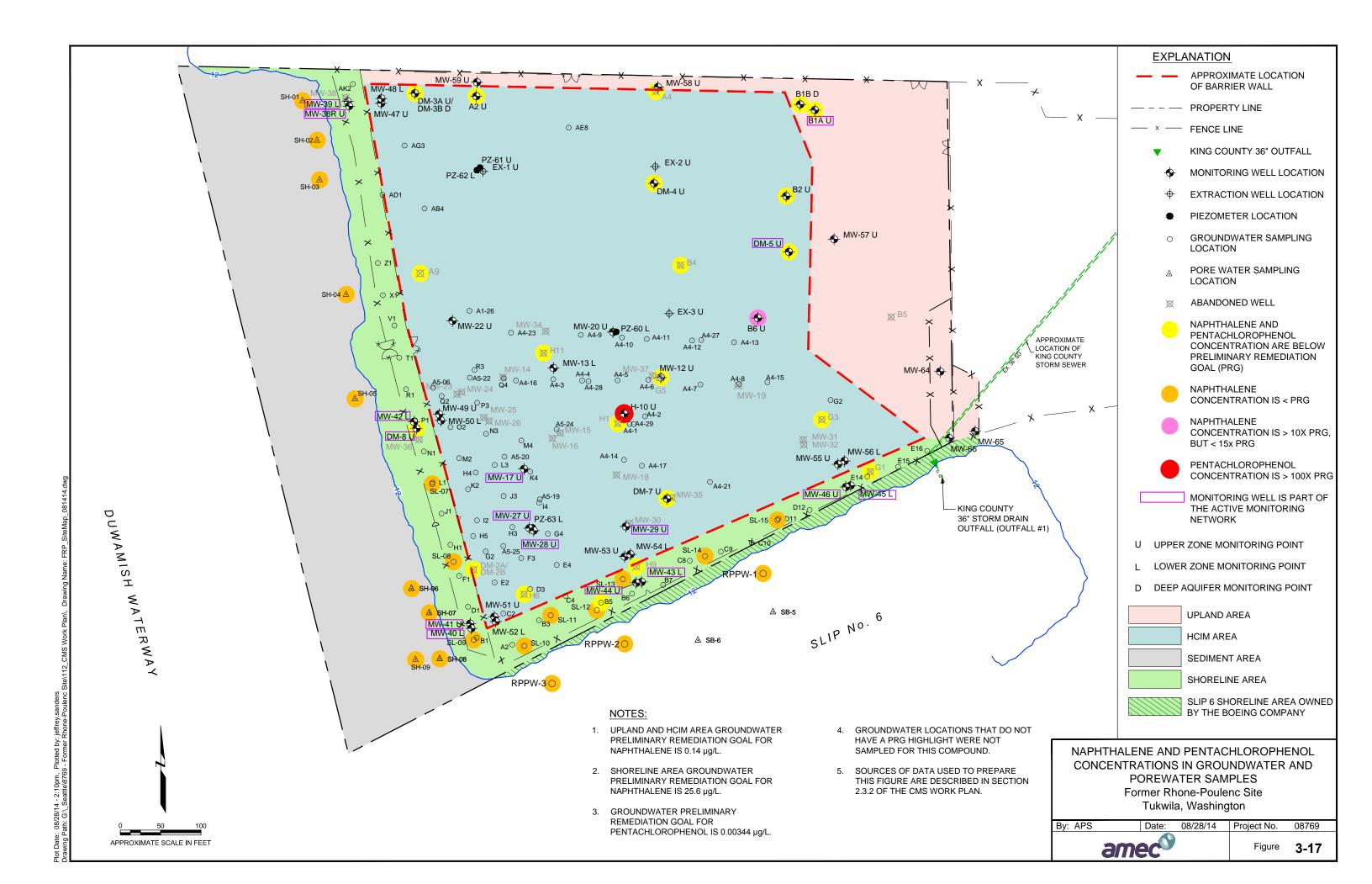


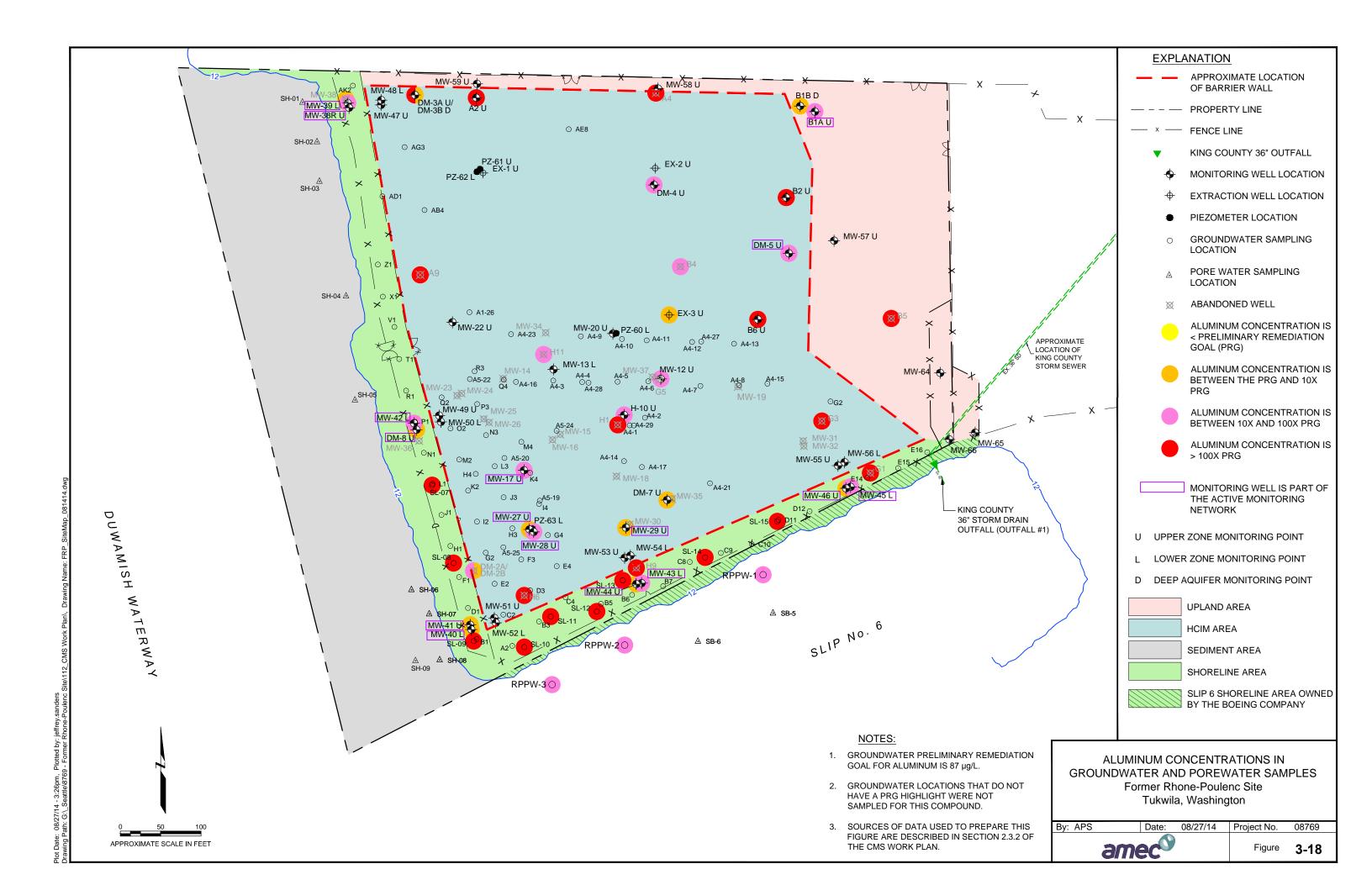


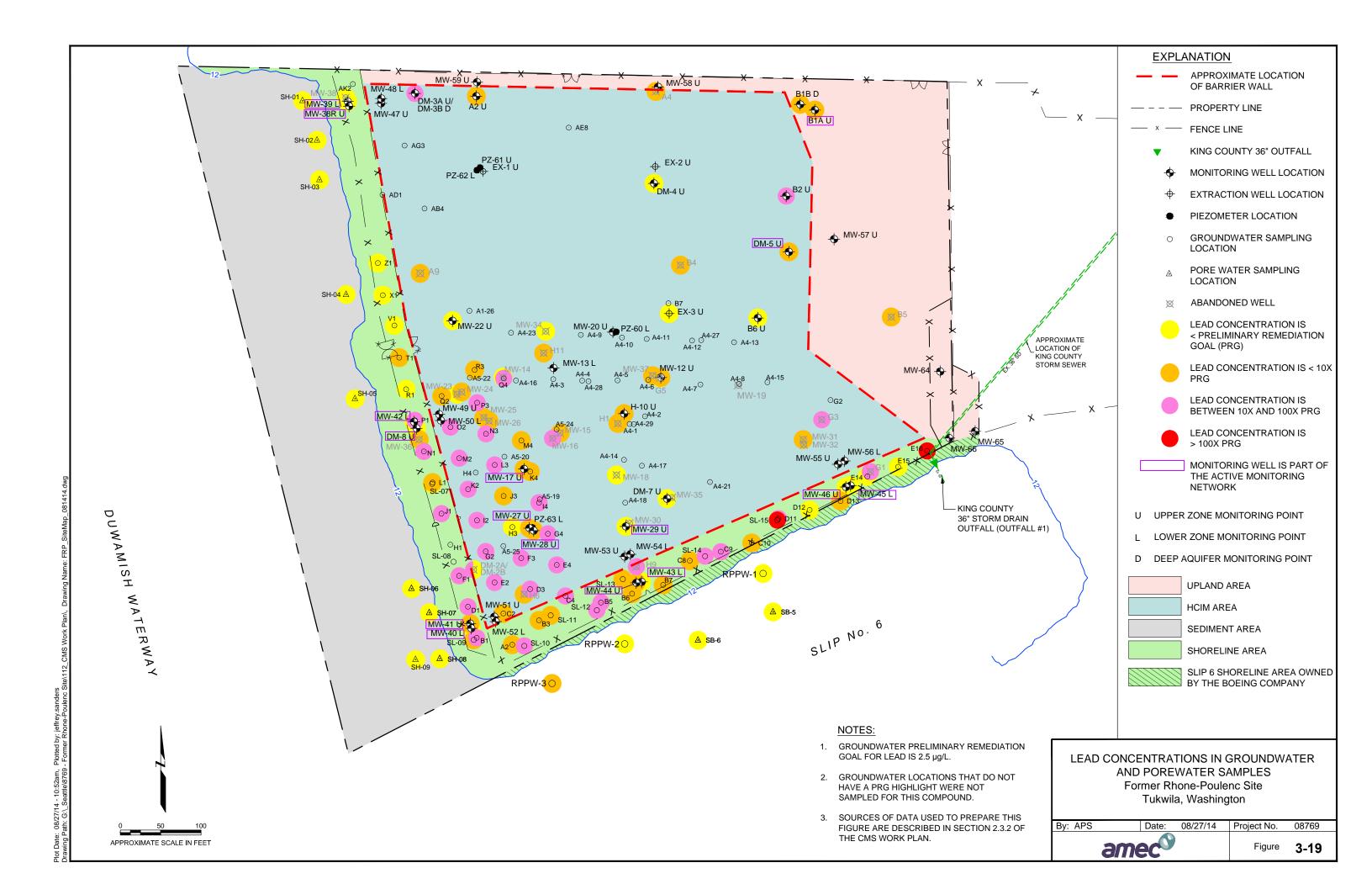


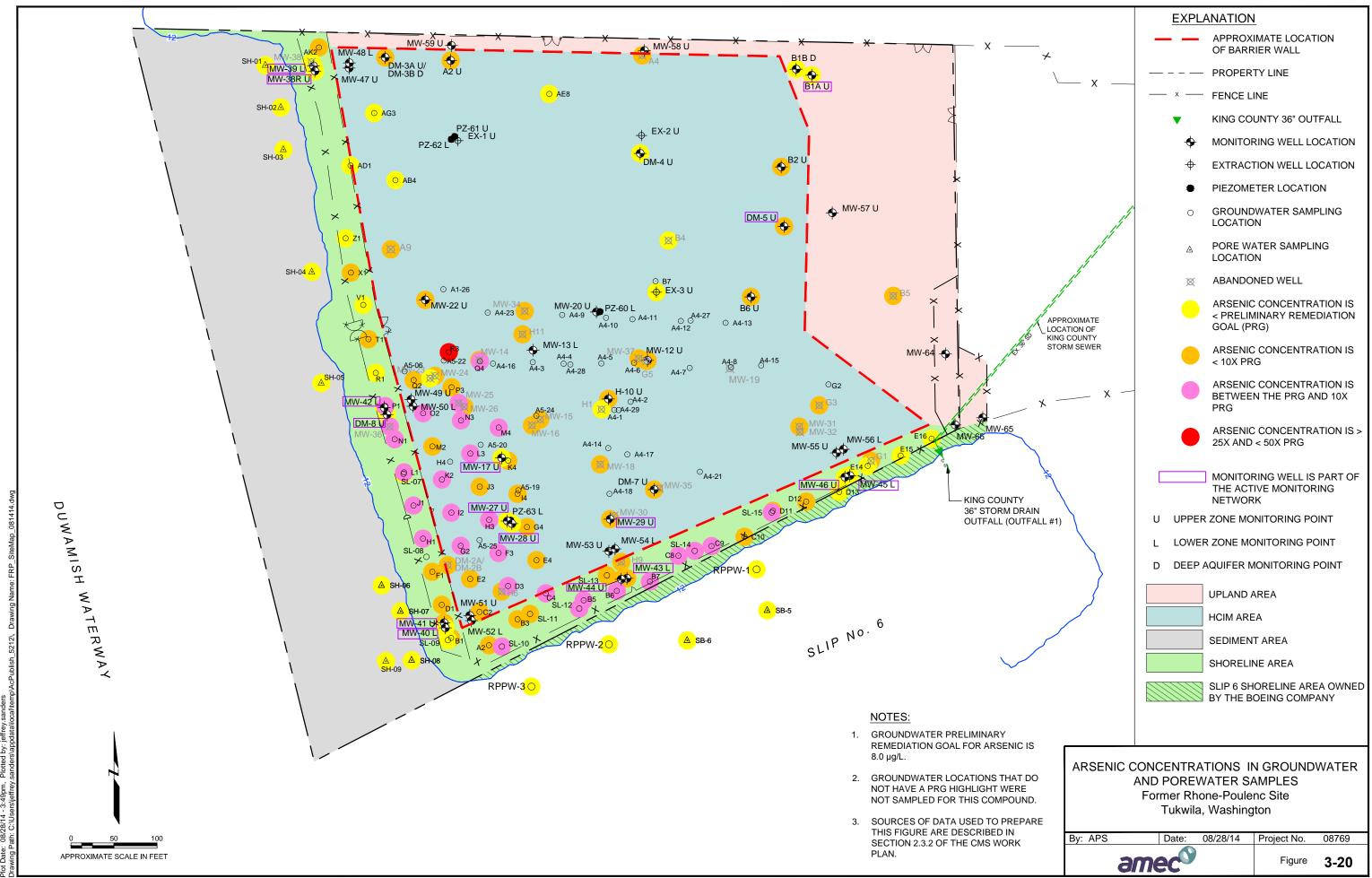


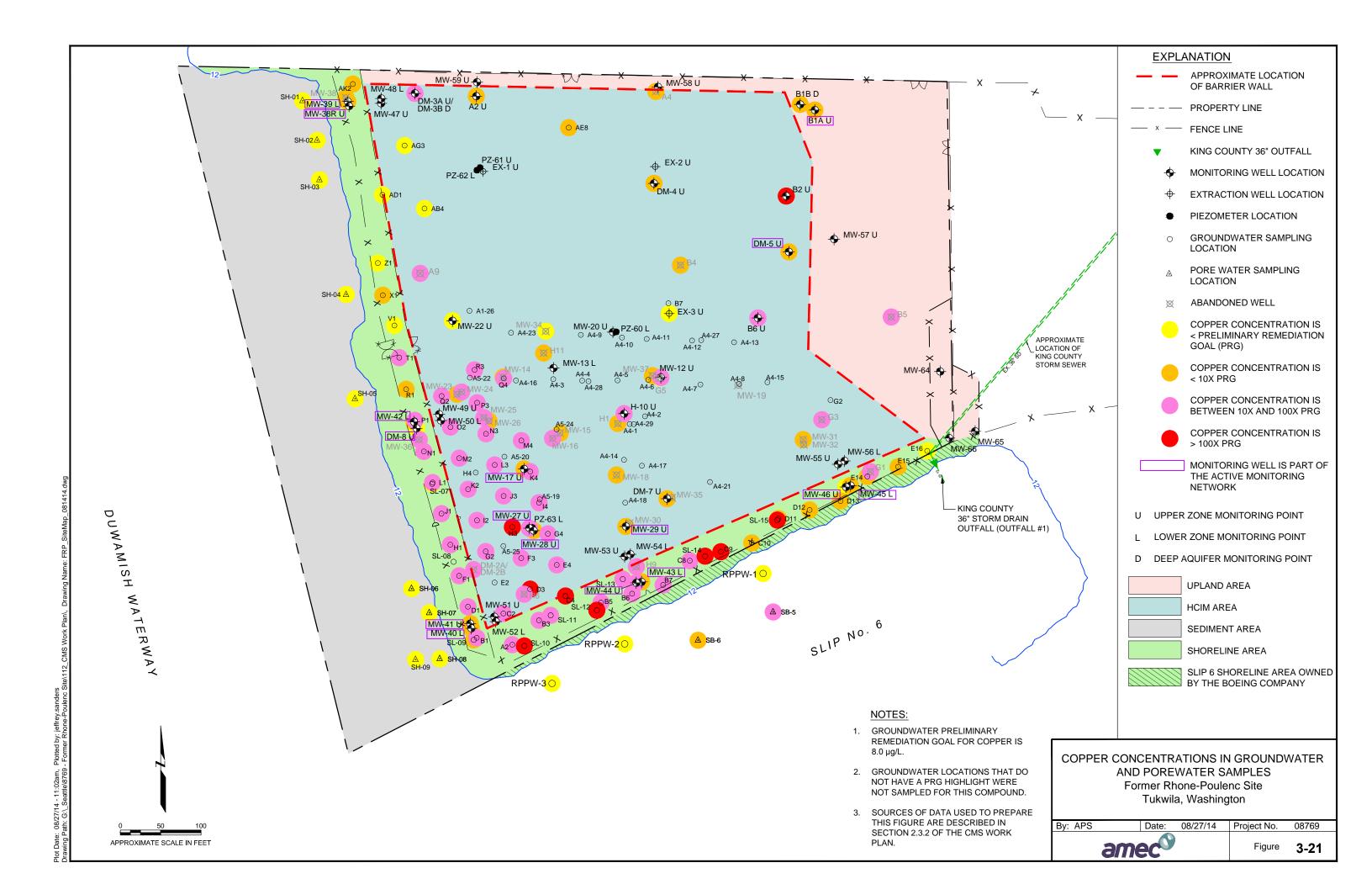


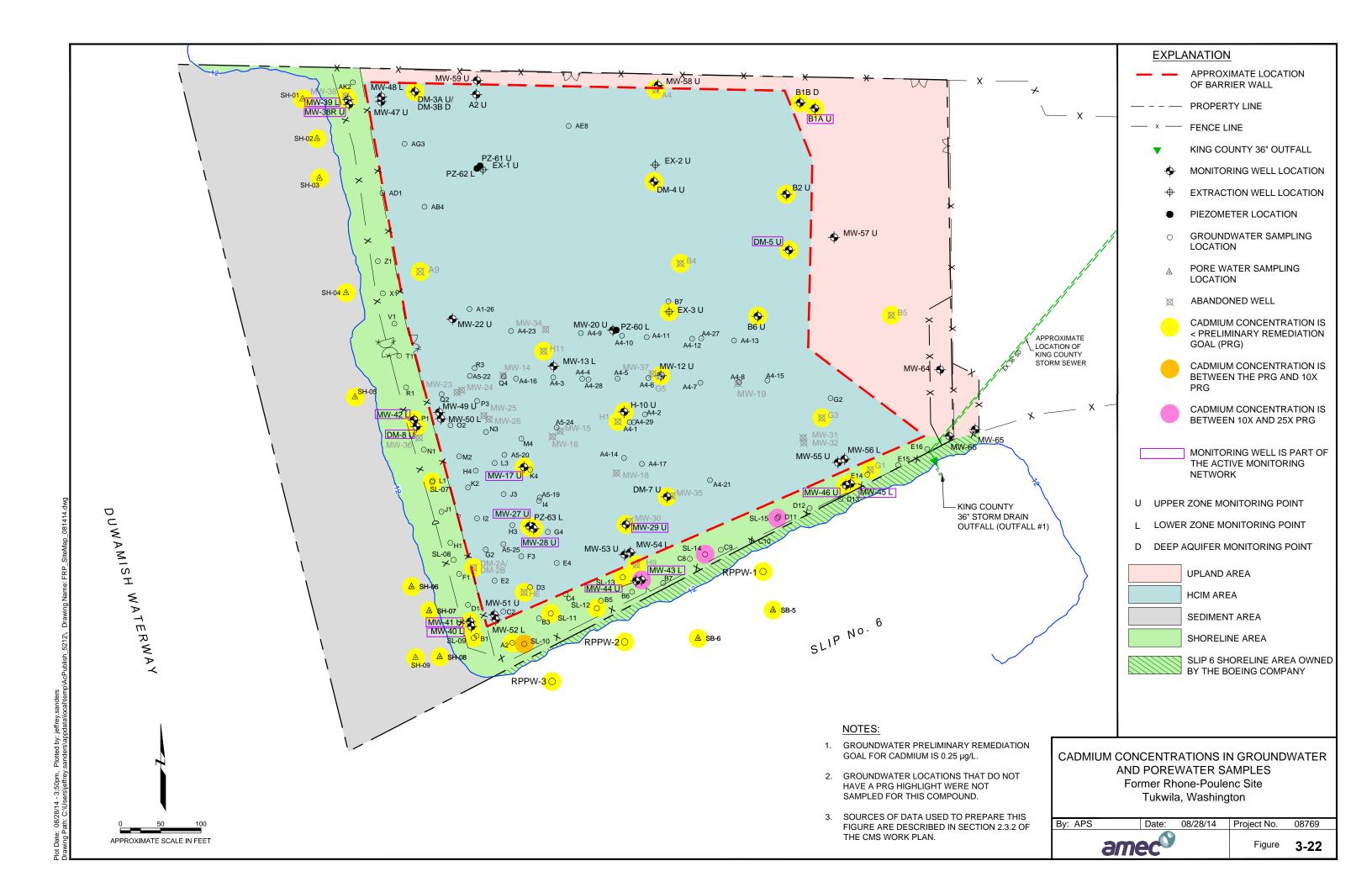


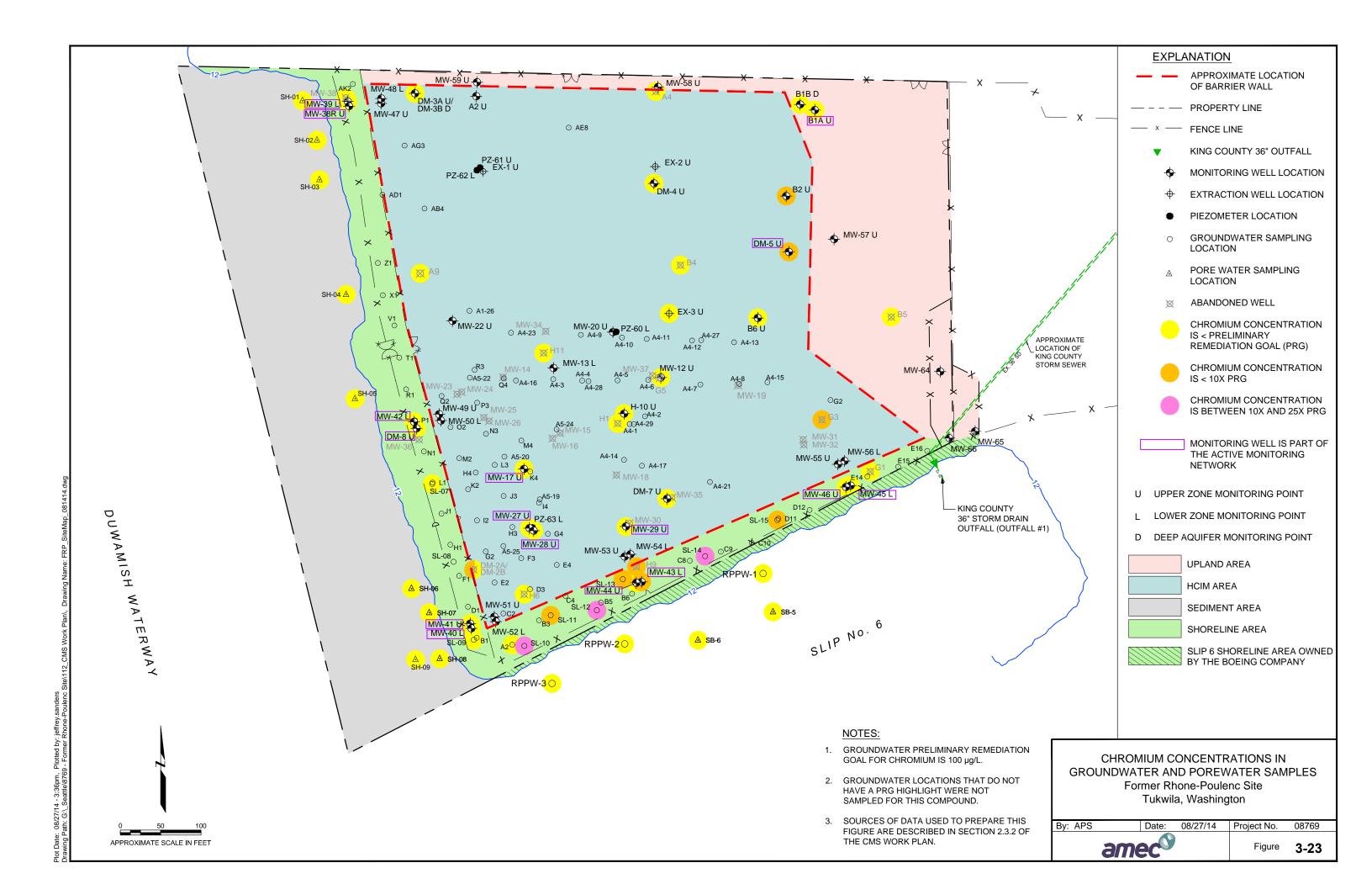


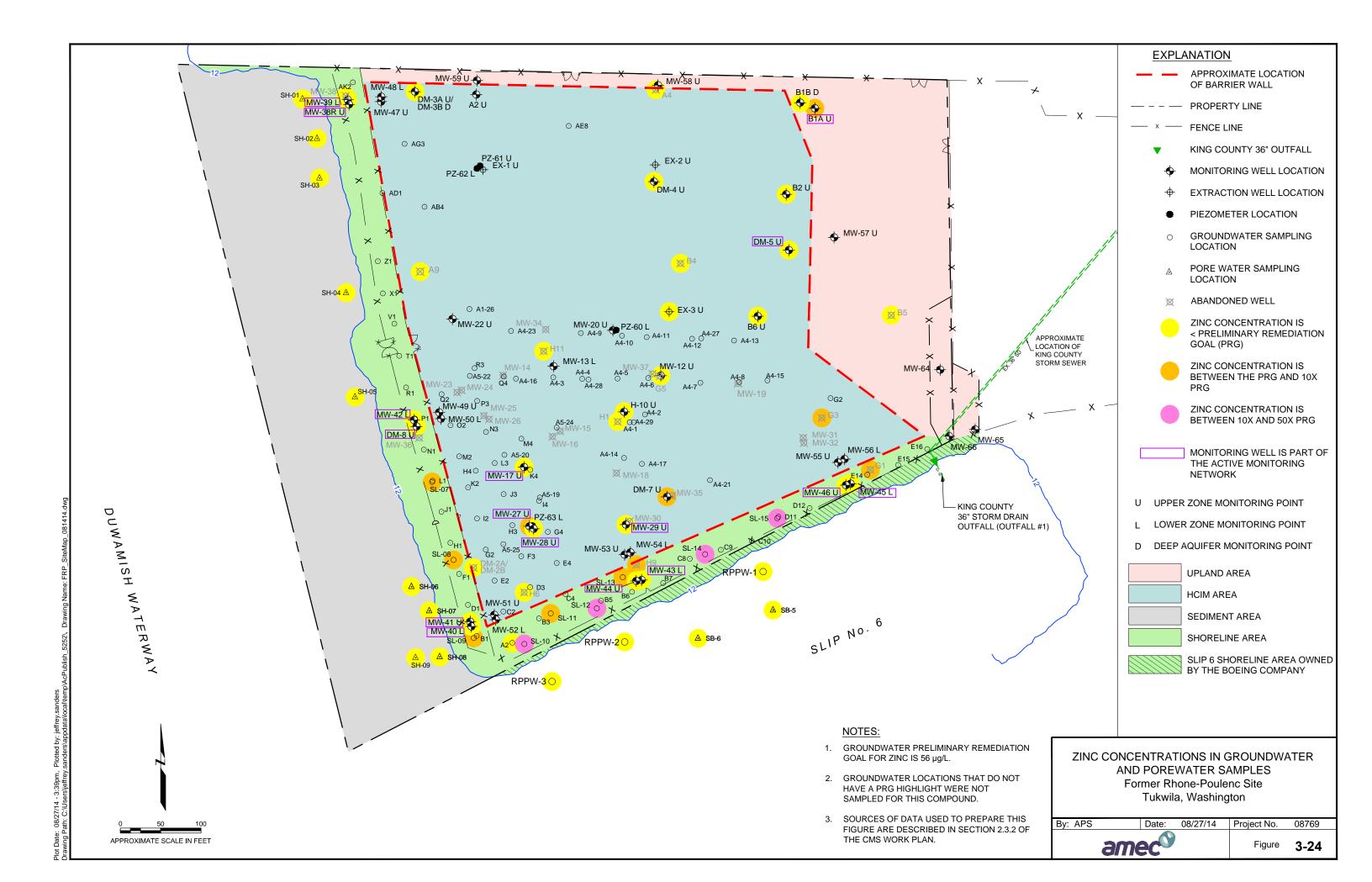


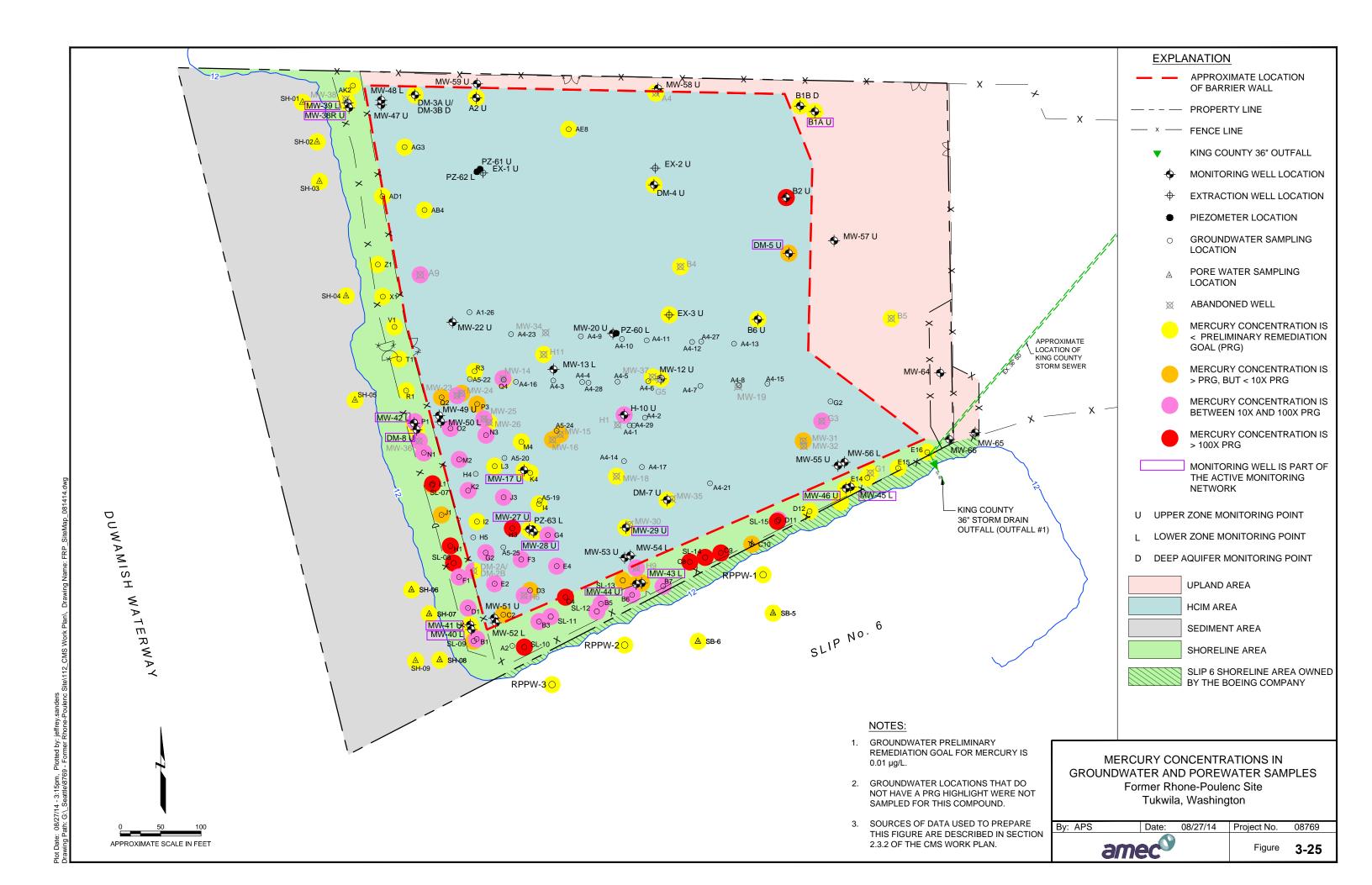


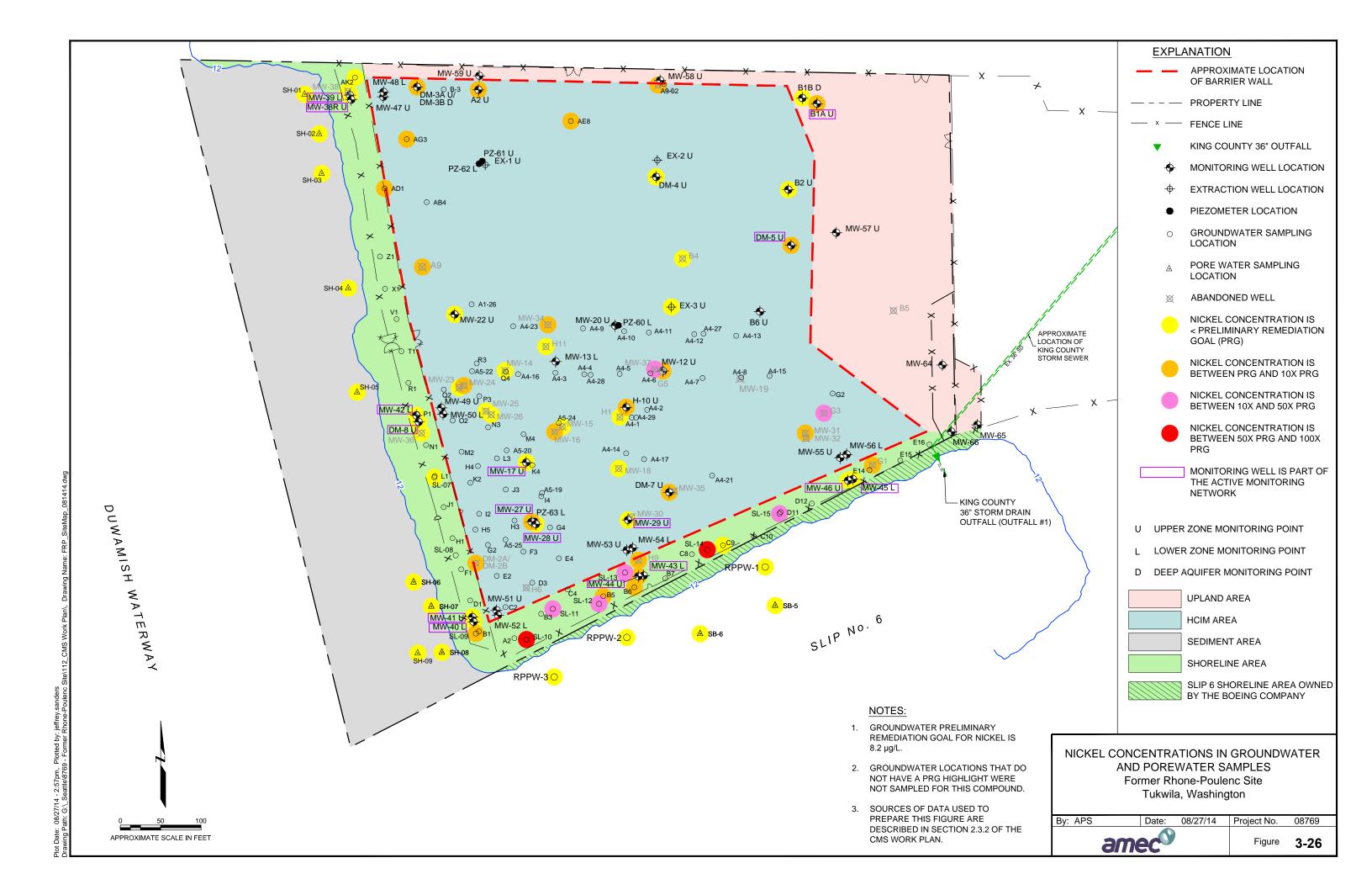


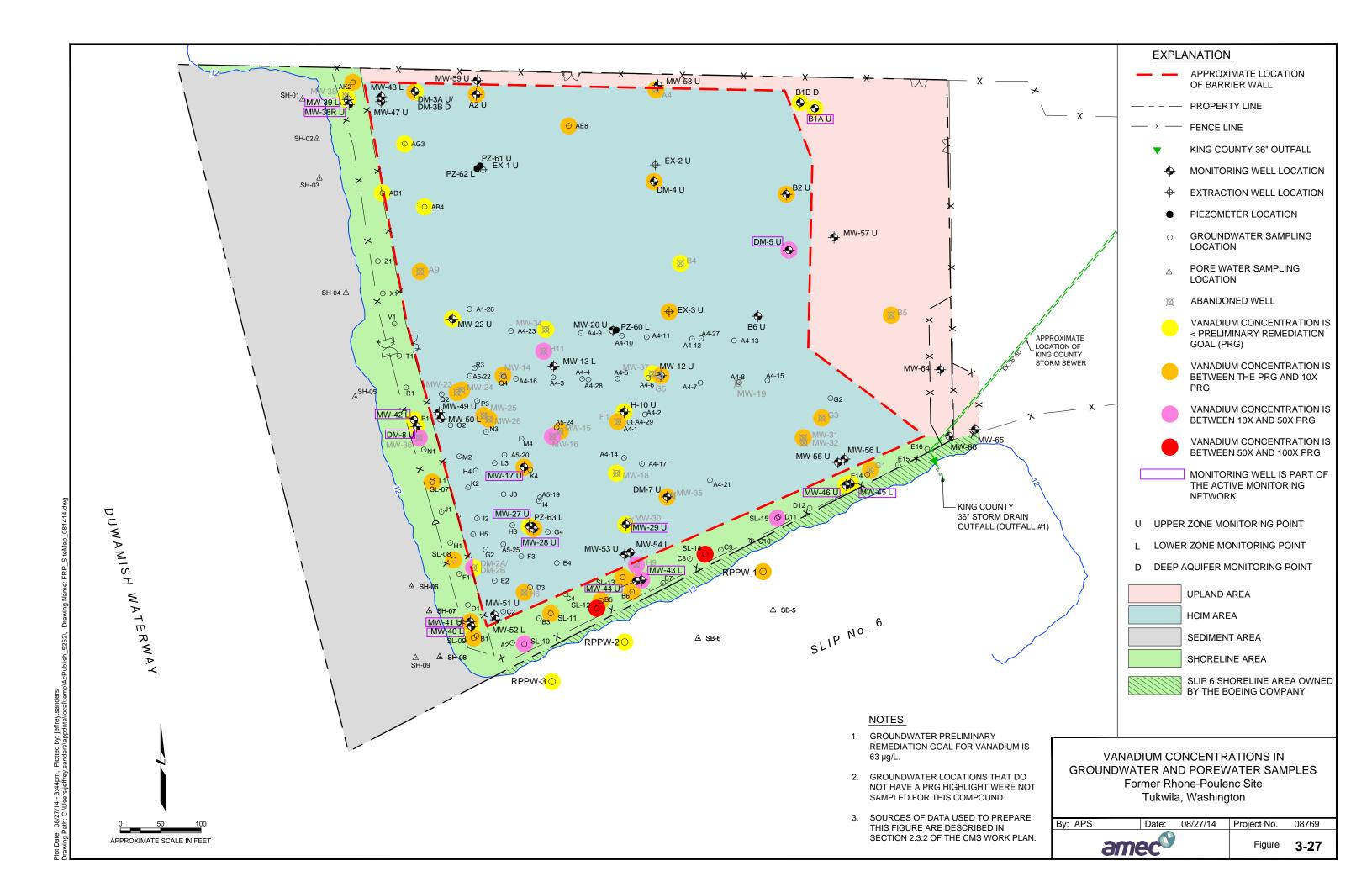


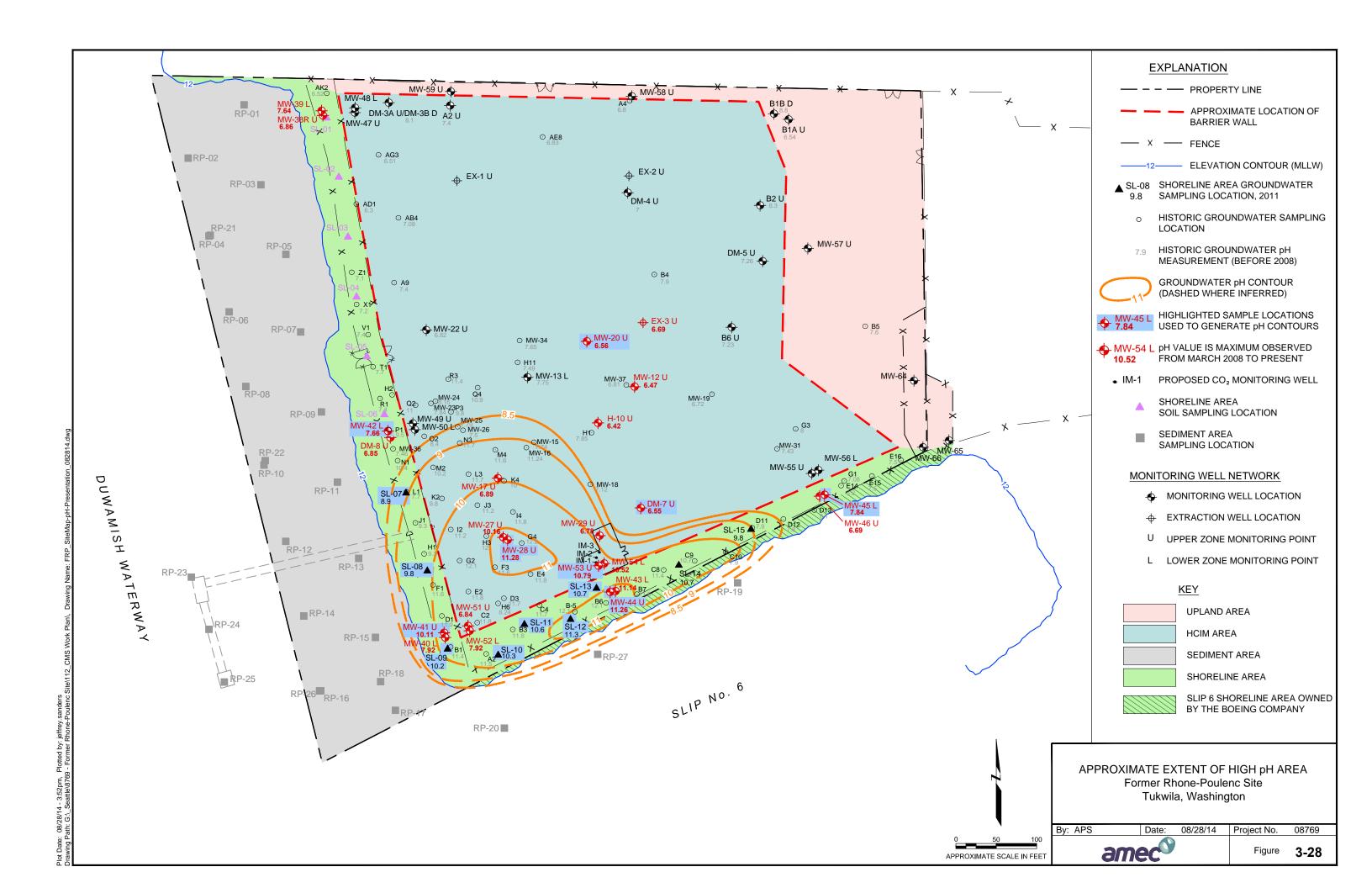


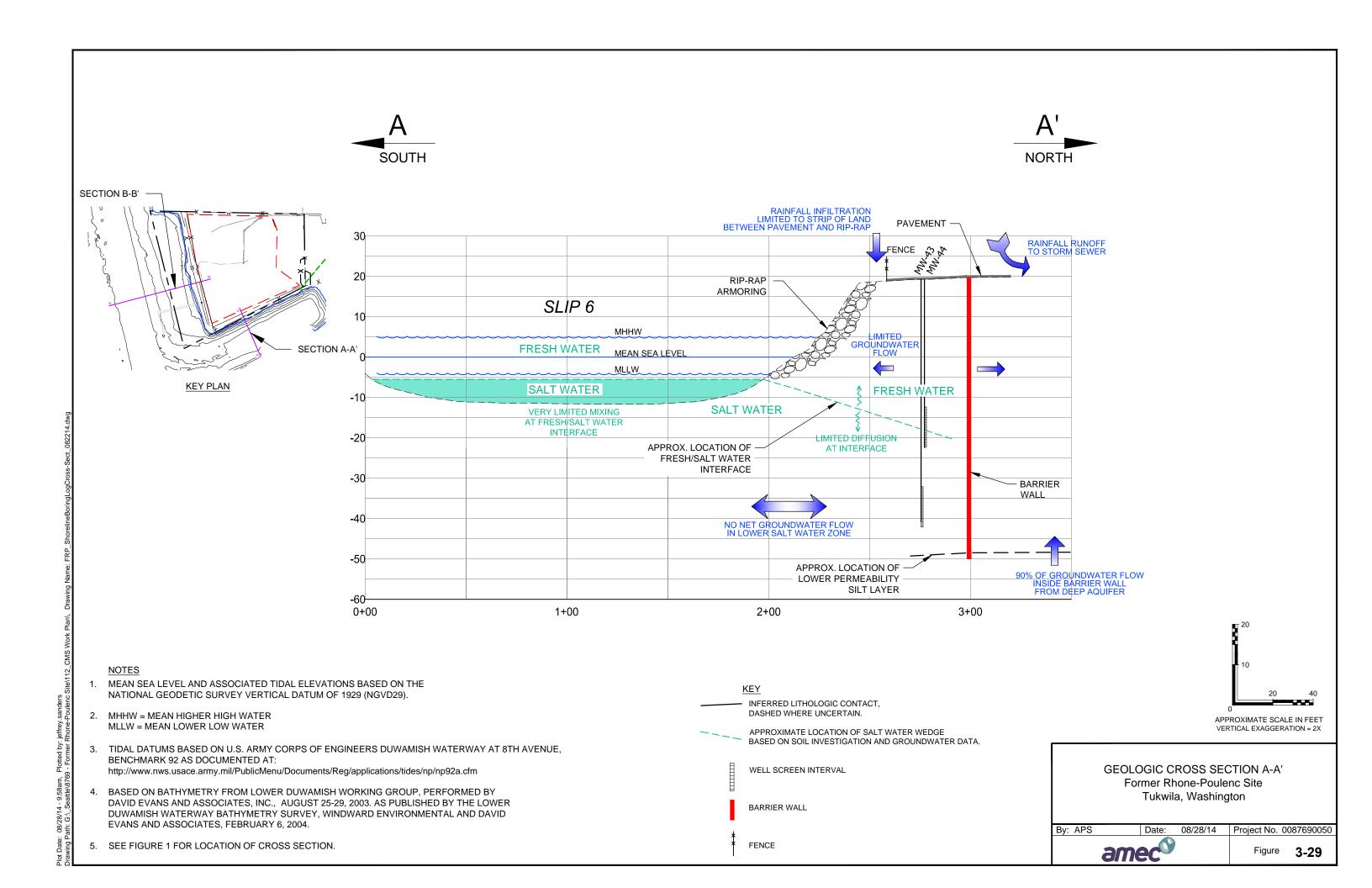


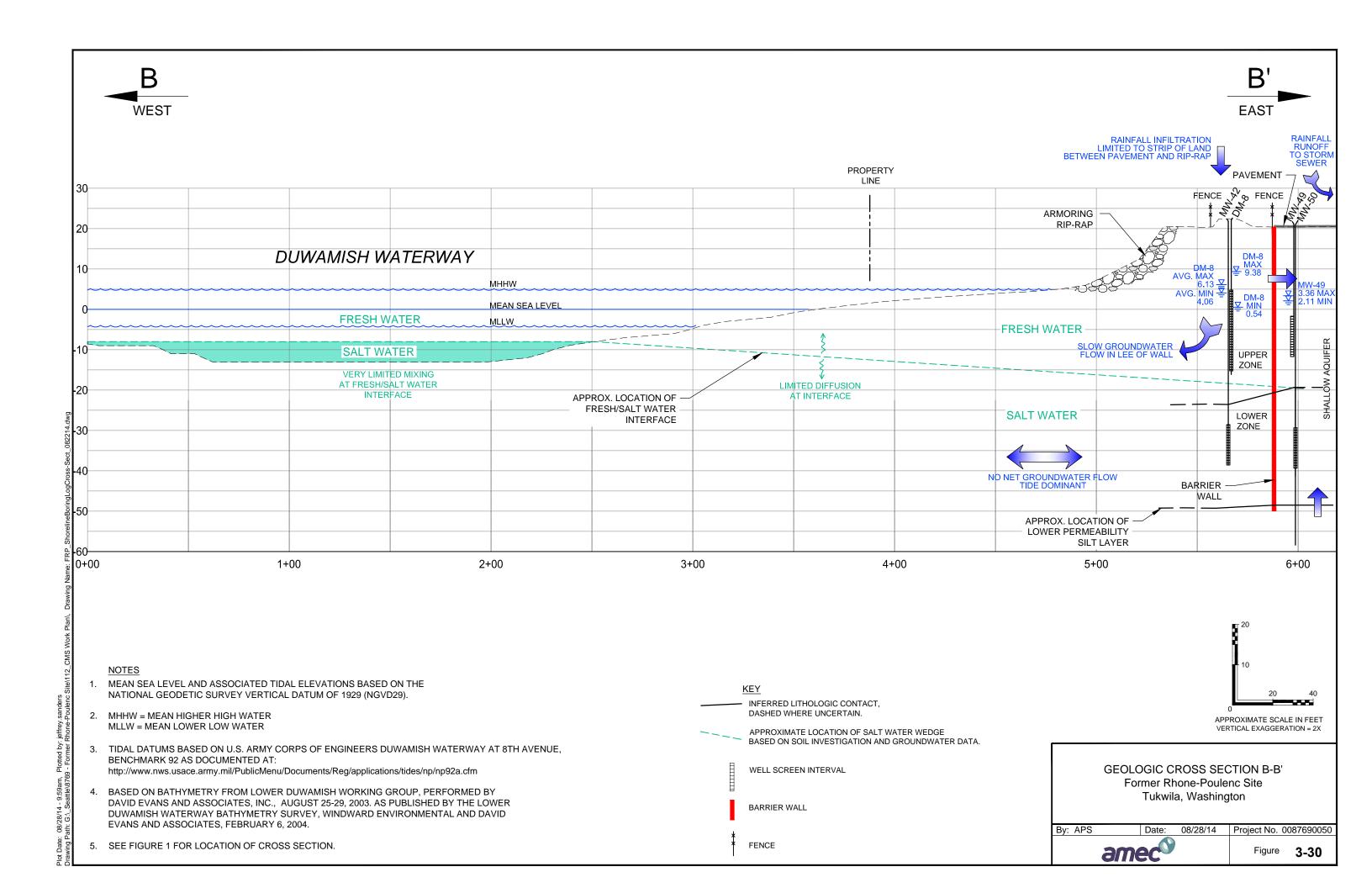


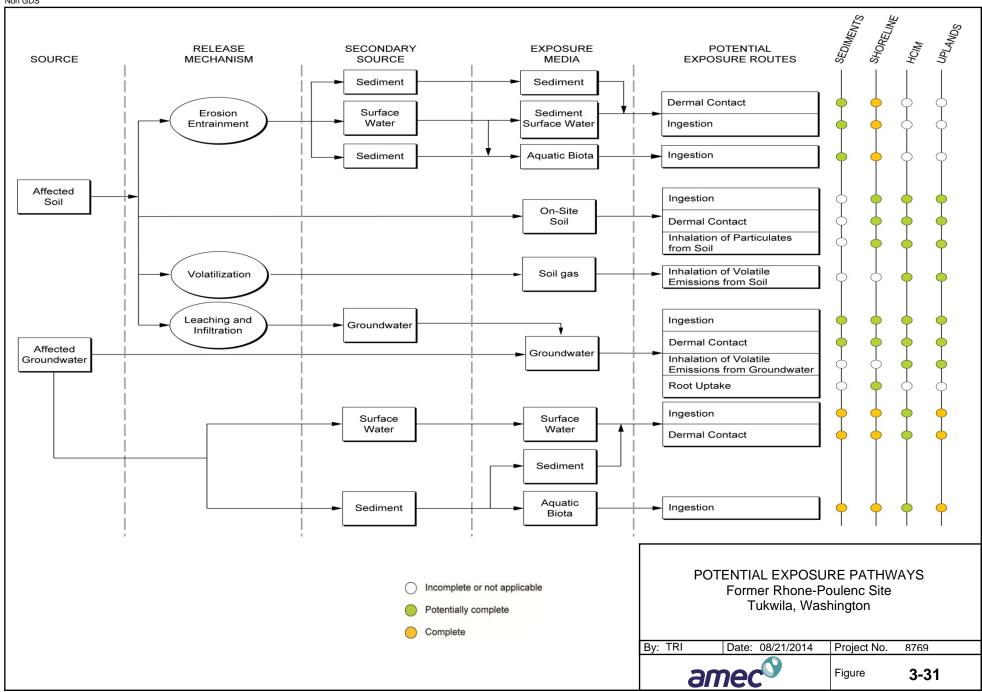


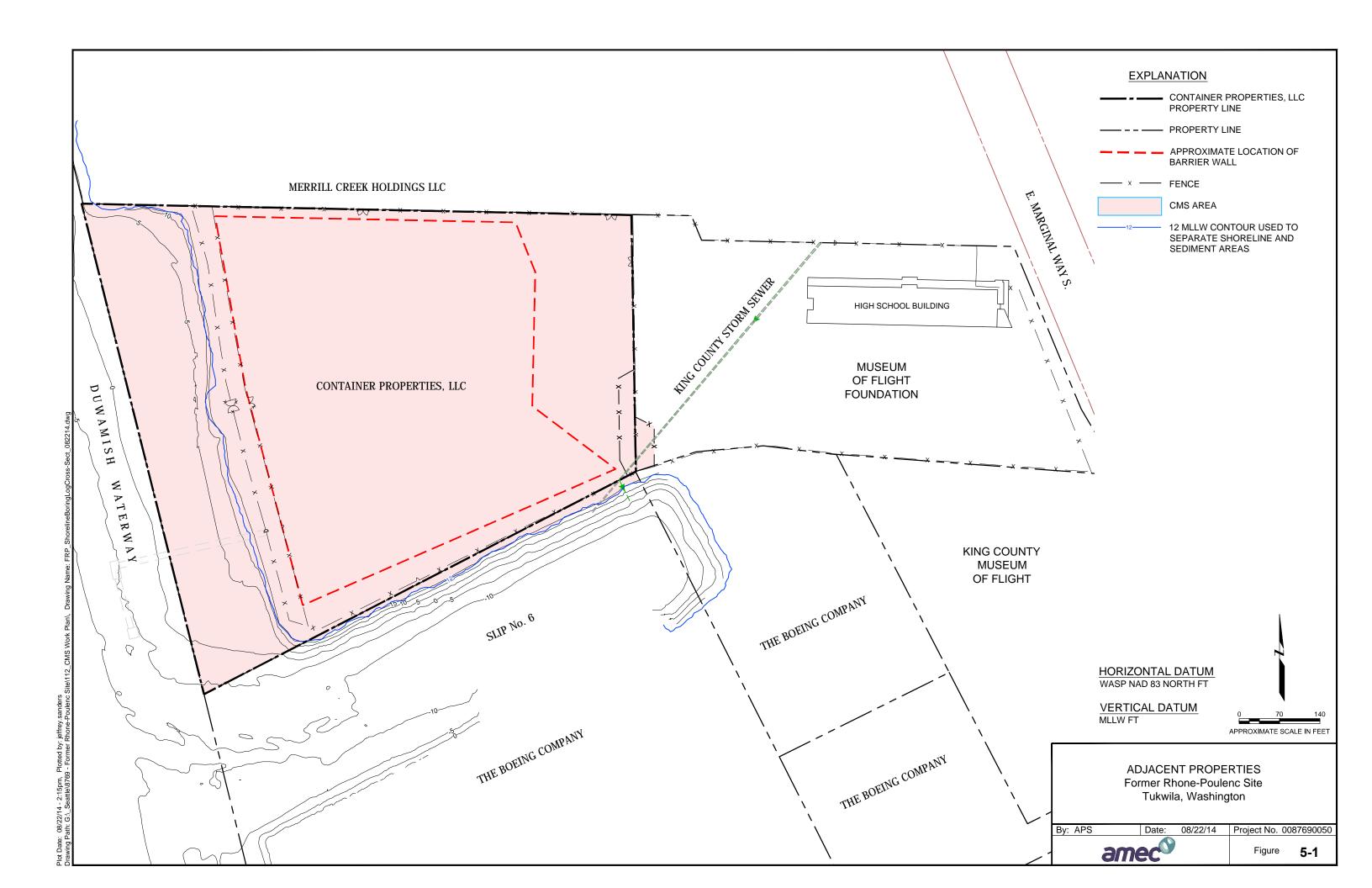


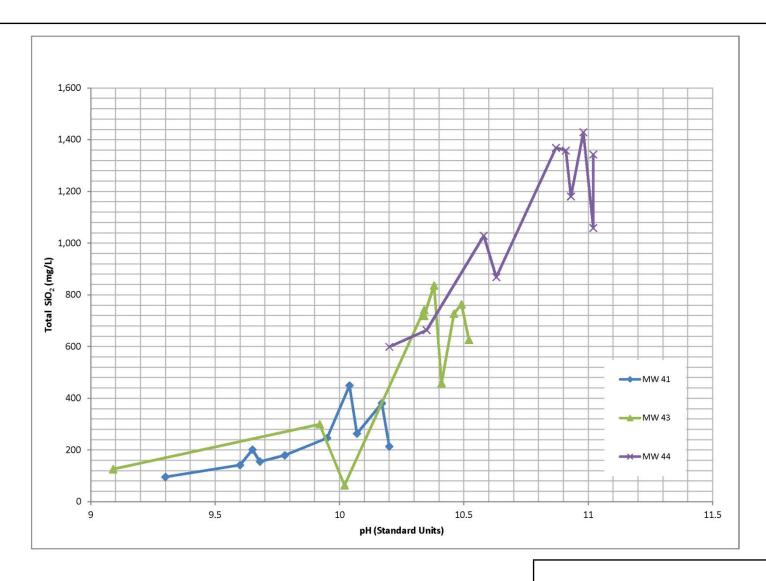




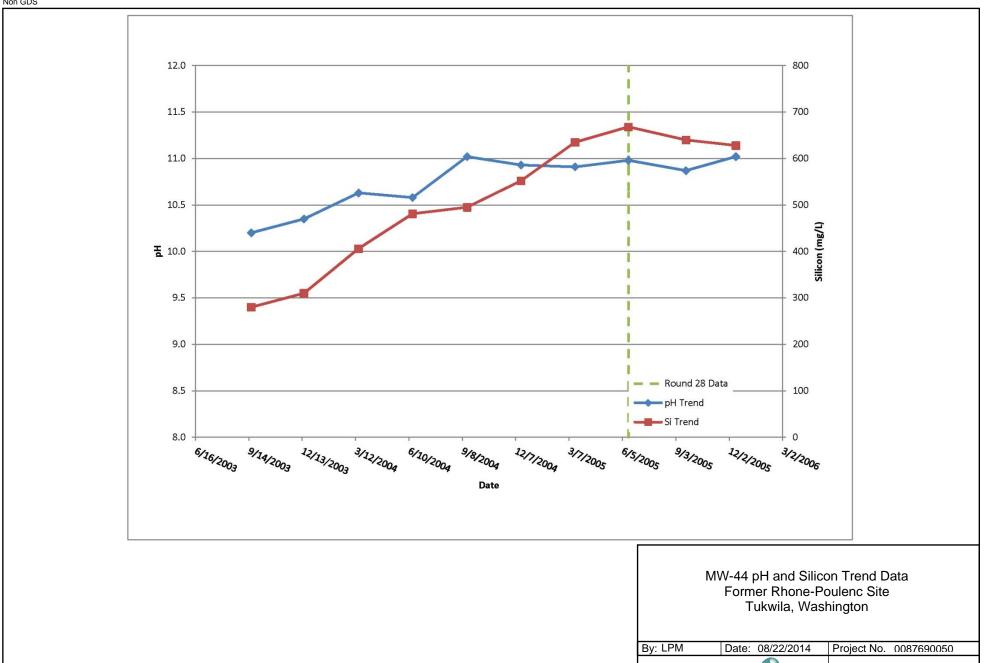






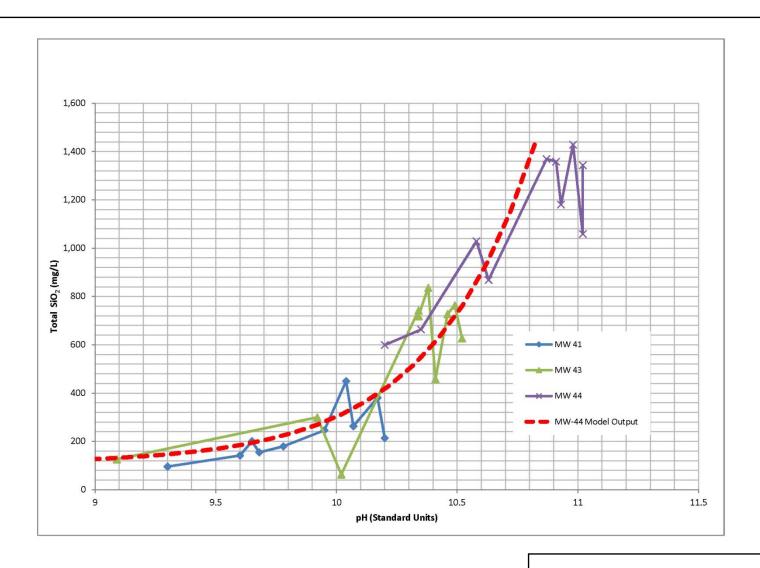


Total SiO<sub>2</sub> vs pH in Shoreline Area Groundwater Former Rhone-Poulenc Site Tukwila, Washington



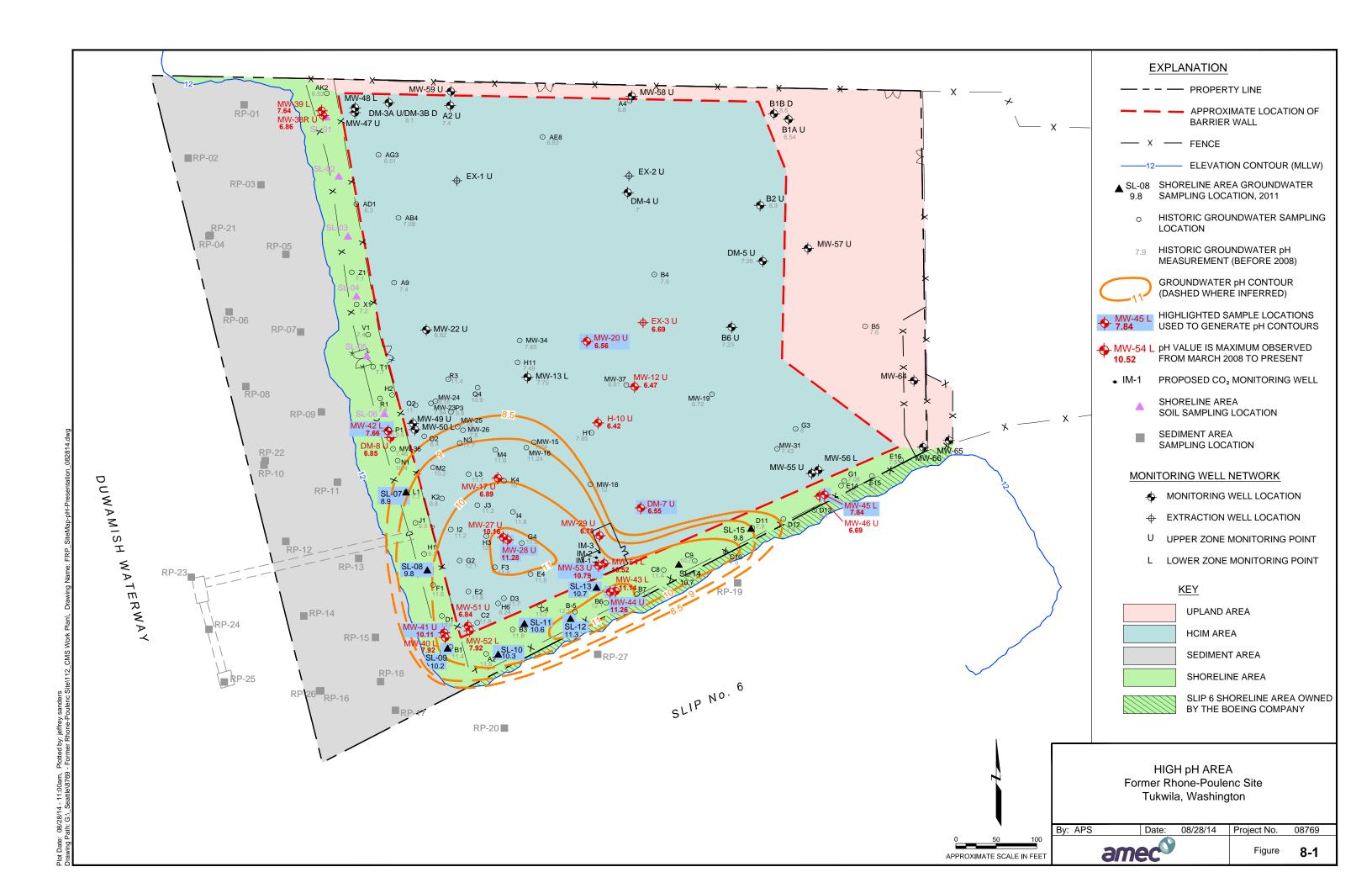
Figure

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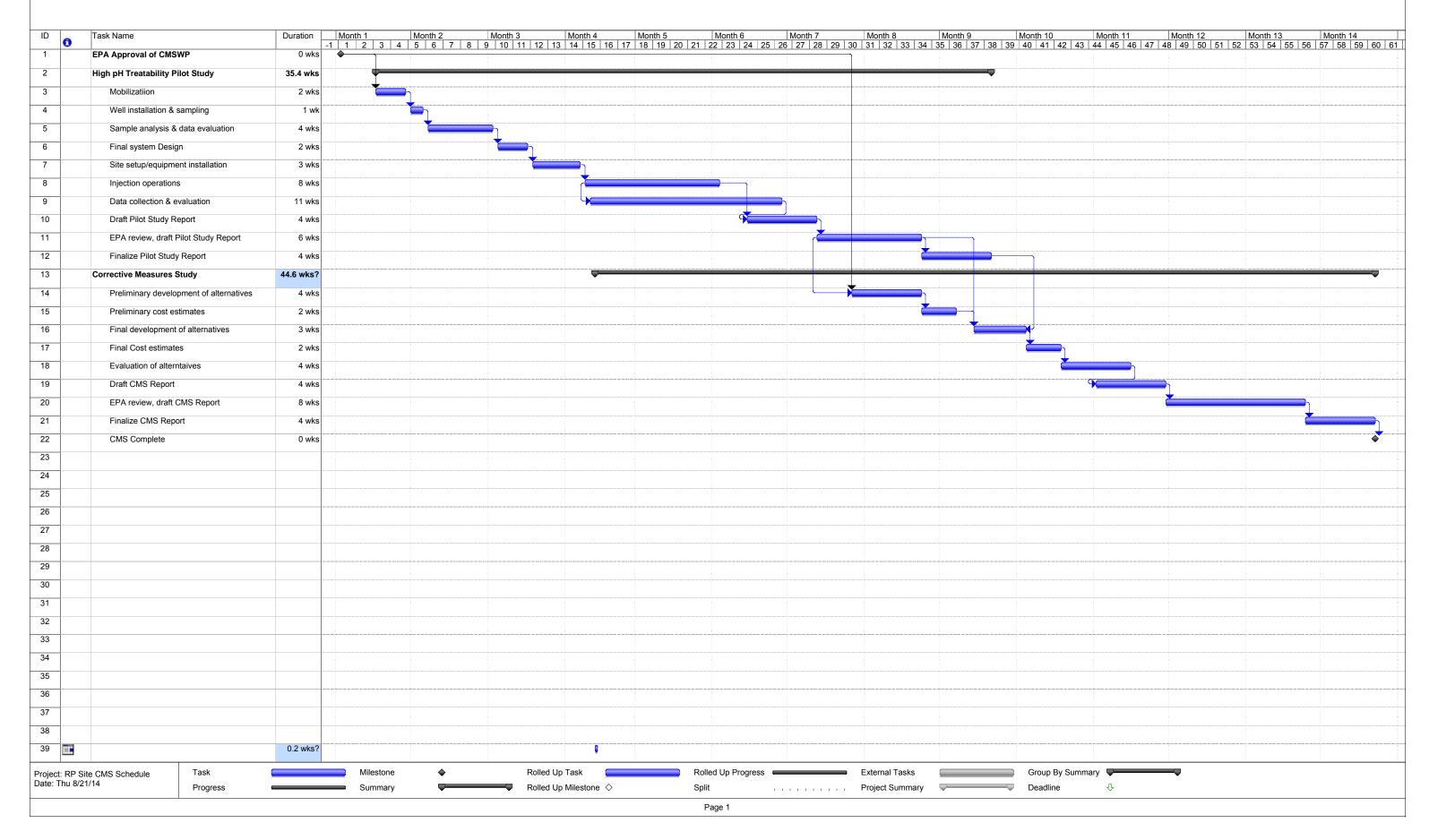


Comparison of Modeled and Measured Total SiO<sub>2</sub> in Shoreline Area Groundwater Former Rhone-Poulenc Site Tukwila, Washington

By: LPM | Date: 08/22/2014 | Project No. 0087690050 |
Figure 5-4



# Figure 10-2: Corrective Measures Study Schedule Former Rhone-Poulenc' Site Tukwila, WA





### **APPENDIX A**

Site Characterization Data



### TOLUENE CONCENTRATIONS IN SOIL 1,2

Site	Event	Date	Compound	Туре	Concentration
A1	1991 SA		Toluene	Organic	0.047
A1-07	Round 1		Toluene	Organic	0.022
A10A201	Round 1		Toluene	Organic	4.5
A10A202	Round 1		Toluene	Organic	0.006
A10A204	Round 1		Toluene	Organic	0.029
A10A602	Round 1		Toluene	Organic	0.003
A10CR04	Round 1		Toluene	Organic	0.001
A10CS01	Round 1		Toluene	Organic	0.004
A10CS03			Toluene	Organic	0.007
A10-MS	Round 1		Toluene	Organic	0.023
A10MS02	Round 1		Toluene	Organic	0.001
A10MS03	Round 1		Toluene	Organic	0.004
	1991 SA		Toluene	Organic	0.0078
A2-01	Round 1		Toluene	Organic	0.043
	Round 1		Toluene	Organic	0.021
	Round 1		Toluene	Organic	0.003
	Round 1		Toluene	Organic	0.022
	Round 1		Toluene	Organic	0.01
	Round 1		Toluene	Organic	0.005
	Round 1		Toluene	Organic	0.014
	Round 1		Toluene	Organic	0.007
	Round 1		Toluene	Organic	0.015
	Round 1		Toluene	Organic	0.004
	Round 1		Toluene	Organic	0.45
	Round 1		Toluene	Organic	3.6
	Round 1		Toluene	Organic	15
	Round 1		Toluene	Organic	0.068
	1991 SA		Toluene	Organic	0.018
	Round 1		Toluene	Organic	0.019
	Round 1		Toluene	Organic	0.003
	Round 1		Toluene	Organic	0.009
	Round 1		Toluene	Organic	0.007
	1991 SA		Toluene	Organic	0.0012 U
	Round 1		Toluene	Organic	0.008
	Round 1		Toluene	Organic	0.35
	Round 1		Toluene	Organic	0.009
	Round 1		Toluene	Organic	7
	Round 1		Toluene	Organic	0.003
	Round 1		Toluene	Organic	0.005
	Round 1		Toluene	Organic	0.009
	Round 1		Toluene	Organic	0.022
	Round 1		Toluene	Organic	0.037
	Round 1		Toluene	Organic	0.009
	Round 1		Toluene	Organic	0.01
A4-30	Round 2		Toluene	Organic	1.9



## TOLUENE CONCENTRATIONS IN SOIL 1,2

Site	Event	Date	Compound	Туре	Concentration
A4-31	Round 2		Toluene	Organic	0.039
A5	1991 SA		Toluene	Organic	0.0014 U
A5-03	Round 1		Toluene	Organic	0.024
A5-04	Round 1		Toluene	Organic	0.044
A5-06	Round 1		Toluene	Organic	0.003
	Round 2		Toluene	Organic	29
	Round 2		Toluene	Organic	0.007
	Round 2		Toluene	Organic	0.002
	Round 2		Toluene	Organic	0.72
	Round 2		Toluene	Organic	0.007
	1991 SA		Toluene	Organic	0.0011 U
	Round 1		Toluene	Organic	0.022
A6-02	Round 1		Toluene	Organic	0.002
	Round 1		Toluene	Organic	0.005
	Round 1		Toluene	Organic	0.025
A6-07	Round 1		Toluene	Organic	0.008
A7	1991 SA		Toluene	Organic	0.0013 U
A7-02	Round 1		Toluene	Organic	0.001
A7-05	Round 1		Toluene	Organic	0.047
A8	1991 SA		Toluene	Organic	0.0071
A8-06	Round 1		Toluene	Organic	0.001
A9	1991 SA		Toluene	Organic	0.0071
A9-01	Round 1		Toluene	Organic	0.025
A9-03	Round 1		Toluene	Organic	0.012
ABG-01	Round 1		Toluene	Organic	0.017
ABG-02	Round 1		Toluene	Organic	0.001
ABG-03	Round 1		Toluene	Organic	0.007
ABG-04	Round 1		Toluene	Organic	0.002
ABG-05	Round 1		Toluene	Organic	0.011
ABG-06	Round 1		Toluene	Organic	0.005
ABG-07	Round 1		Toluene	Organic	0.004
B-1	HCIM	6/1/2002	Toluene	Organic	1.1 U
B10	1991 SA		Toluene	Organic	4.2
	1991 SA		Toluene	Organic	73
	1991 SA		Toluene	Organic	0.0016 U
	1991 SA		Toluene	Organic	45
	1991 SA		Toluene	Organic	0.0012
B15	1991 SA		Toluene	Organic	0.0077
B1A	1991 SA		Toluene	Organic	0.032
B2	1991 SA		Toluene	Organic	8
	1991 SA		Toluene	Organic	0.019
B-3	HCIM	6/1/2002	Toluene	Organic	1.3 U
B4	1991 SA		Toluene	Organic	2
	HCIM	6/1/2002	Toluene	Organic	1.4 U
B5	1991 SA		Toluene	Organic	0.018



### TOLUENE CONCENTRATIONS IN SOIL 1,2

Site	Event	Date	Compound	Туре	Concentration
B-5	HCIM	6/1/2002	Toluene	Organic	1.3 U
B6	1991 SA		Toluene	Organic	0.025
B-6B	HCIM	6/1/2002		Organic	1.4 U
B7	1991 SA		Toluene	Organic	0.0041
	HCIM	6/1/2002	Toluene	Organic	2.9
	1991 SA		Toluene	Organic	13
	1991 SA		Toluene	Organic	4
	1991 SA		Toluene	Organic	0.0092
	1991 SA		Toluene	Organic	0.0038
	1991 SA		Toluene	Organic	0.0033
D1	1991 SA		Toluene	Organic	0.023
D2			Toluene	Organic	0.048
D4			Toluene	Organic	0.027
E2			Toluene	Organic	0.0012
E3	1991 SA		Toluene	Organic	0.0069
F1			Toluene	Organic	0.0013 U
F2	1991 SA		Toluene	Organic	0.0018
G1	1991 SA		Toluene	Organic	0.001 U
G10	1991 SA		Toluene	Organic	0.0085
G2	1991 SA		Toluene	Organic	0.0017
G3	1991 SA		Toluene	Organic	0.0042
G4	1991 SA		Toluene	Organic	0.0009
G5	1991 SA		Toluene	Organic	0.048
G6	1991 SA		Toluene	Organic	0.0011 U
G7	1991 SA		Toluene	Organic	0.013
G8	1991 SA		Toluene	Organic	0.0031
G9	1991 SA		Toluene	Organic	0.0051
H1			Toluene	Organic	3.7
H11			Toluene	Organic	27
H2	1991 SA		Toluene	Organic	0.0045
	1991 SA		Toluene	Organic	0.0016
	1991 SA		Toluene	Organic	0.0068
H5	1991 SA		Toluene	Organic	0.0052
	1991 SA		Toluene	Organic	0.014
	1991 SA		Toluene	Organic	0.0054
	1991 SA		Toluene	Organic	0.54
	1991 SA		Toluene	Organic	0.0007
MW-43		6/1/2002	Toluene	Organic	1.3 U
MW-45		6/1/2002	Toluene	Organic	1.3 U
	Round 1		Toluene	Organic	180
	Round 1		Toluene	Organic	3600
	Round 1		Toluene	Organic	120
	Round 1		Toluene	Organic	180
	Round 1		Toluene	Organic	4900
A4-04	Round 1		Toluene	Organic	4400



### **TOLUENE CONCENTRATIONS IN SOIL 1,2**

Former Rhone-Poulenc Site Tukwila, Washington

Site	Event	Date	Compound	Type	Concentration
A4-05	Round 1		Toluene	Organic	1800
B13	1991 SA		Toluene	Organic	5400
G5	1991 SA		Toluene	Organic	5400
H1	1991 SA		Toluene	Organic	28000
H11	1991 SA		Toluene	Organic	2700

#### **Notes**

- 1. All units in mg/kg (milligrams per kilogram).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented

#### Abbreviations

1991 SA = 1991 Site Assessment HCIM = Hydraulic Control Interim Measure



### TPH CONCENTRATIONS IN SOIL 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Event	Date	Compound	Туре	Concentration
A02-05-08	Round 1		Benzene		0.017
A02-06-05	Round 1		Benzene		0.002
A02-09-04	Round 1		Ethylbenzene		0.022
A02-11-01	Round 1		Ethylbenzene		2.5
A02-12-01	Round 1		Ethylbenzene		0.92
A02-13-03	Round 1		Ethylbenzene		6.4
A04-01-05	Round 1		Ethylbenzene		2
A04-04-01	Round 1		Ethylbenzene		1.1
A04-04-03	Round 1		Ethylbenzene		0.91
A04-04-06	Round 1		Ethylbenzene		0.29
A04-05-06	Round 1		Ethylbenzene		2.3
A04-06-06			Benzene		0.23
A04-06-06	Round 1		Ethylbenzene		0.27
A04-07-06	Round 1		Benzene		0.003
A04-07-06	Round 1		Ethylbenzene		0.013
A3-02	Round 1		TPH	Organic	635
A3-03	Round 1		TPH	Organic	175
A3-04	Round 1		TPH	Organic	88.8
A4-30	Round 2		TPH	Organic	81
A4-31	Round 2		TPH	Organic	380
A5-10	Round 2		TPH	Organic	8200
A6-01	Round 1		TPH	Organic	645
A6-05	Round 1		TPH	Organic	227
	Round 1		TPH	Organic	92.7
	Round 1		TPH	Organic	151
A8-06	Round 1		TPH	Organic	338
	HCIM		TPH Diesel Range	Organic	69
	HCIM		TPH Diesel Range	Organic	8.5
	HCIM		TPH Diesel Range	Organic	34
MW-39			TPH Diesel Range	Organic	430
MW-39			TPH Gas Range	Organic	1200
	AMEC Sediment and Shoreline Investigation		Diesel Range Organics		1000
	AMEC Sediment and Shoreline Investigation		Diesel Range Organics		7.2
	AMEC Sediment and Shoreline Investigation		Diesel Range Organics		6.3 U
	AMEC Sediment and Shoreline Investigation		Diesel Range Organics		9.2
	AMEC Sediment and Shoreline Investigation		Diesel Range Organics		6
	AMEC Sediment and Shoreline Investigation		Diesel Range Organics		27
SL-06	AMEC Sediment and Shoreline Investigation	8/29/2011	Diesel Range Organics		69

#### <u>Notes</u>

- 1. All units in mg/kg (milligrams per kilogram).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented

#### **Abbreviations**

HCIM = Hydraulic Control Interim Measure TPH = total petroleum hydrocarbon



### PCB CONCENTRATIONS IN SOIL AND SEDIMENT 1,2

		1	Result		1
			κθευίτ (μg/kg Dry	mg/kg Dry	
Site	Date	Analyte	(μg/kg bly Weight)	Weight	mg/Kg OC
Oite	Date	Sediment		Weight	mg/rtg 00
RP-01 SURFACE	10/12/2011	Total PCBs	127	0.127	T 5.04
RP-01 SURFACE	10/12/2011	Total PCBs	83	0.083	5.04 7.61
RP-02 SURFACE	10/12/2011	Total PCBs	138	0.083	7.75
RP-02 SURFACE	10/12/2011	Total PCBs	56	0.136	3.22
RP-03 SURFACE	10/19/2011	Total PCBs	156	0.056	6.09
RP-04 SURFACE	10/12/2011	Total PCBs	116	0.136	7.34
RP-04 DEEP	10/20/2011	Total PCBs	12	0.012	0.58
RP-05 SURFACE	10/20/2011	Total PCBs	122	0.122	5.65
RP-05 DEEP	10/12/2011	Total PCBs	1660	1.66	100
RP-06 SURFACE	10/12/2011	Total PCBs	141	0.141	9.22
RP-06 DEEP	10/20/2011	Total PCBs	67	0.067	3.35
RP-07 SURFACE	10/20/2011	Total PCBs	103	0.103	5.42
RP-07 DEEP	10/18/2011	Total PCBs	228	0.103	17.01
RP-08 SURFACE	10/12/2011	Total PCBs	101	0.101	5.87
RP-08 DEEP	10/12/2011		101	0.101	
RP-09 SURFACE		Total PCBs	96		5.00
	10/12/2011 10/19/2011	Total PCBs		0.096	5.61
RP-09 DEEP		Total PCBs	160	0.16	12.12
RP-10 SURFACE	10/12/2011	Total PCBs	1040	1.04	59.77
RP-10 DEEP	10/21/2011	Total PCBs	218	0.218	8.86
RP-11 SURFACE	10/13/2011	Total PCBs	210	0.21	21.63
RP-12 SURFACE	10/13/2011	Total PCBs	117	0.117	4.40
RP-12 DEEP	10/20/2011	Total PCBs	33	0.033	1.36
RP-13 SURFACE	10/13/2011	Total PCBs	58	0.058	2.14
RP-13 DEEP	10/19/2011	Total PCBs	55	0.055	5.34
RP-14 SURFACE	10/13/2011	Total PCBs	23	0.023	0.97
RP-14 DEEP	10/21/2011	Total PCBs	65	0.065	2.23
RP-15 SURFACE	10/13/2011	Total PCBs	60	0.06	3.09
RP-16 SURFACE	10/14/2011	Total PCBs	27	0.027	0.80
RP-16 DEEP	10/21/2011	Total PCBs	180	0.18	7.76
RP-17 SURFACE	10/13/2011	Total PCBs	12	0.012	0.61
RP-17 DEEP	10/21/2011	Total PCBs	231	0.231	11.97
RP-18 SURFACE	10/13/2011	Total PCBs	43	0.043	3.94
RP-21 SURFACE	10/12/2011	Total PCBs	96	0.096	6.11
RP-22 SURFACE	10/13/2011	Total PCBs	1070	1.07	44.03
RP-26 SURFACE	10/14/2011	Total PCBs	31	0.031	1.19
SH-1 LOWER		Total PCBs	320	0.32	49.16
SH-2 LOWER	8/24/2004	Total PCBs	145	0.145	7.55
SH-3 UPPER	8/24/2004	Total PCBs	19 U	0.019	NC
SH-3 LOWER	8/24/2004	Total PCBs	19	0.019	11.95
SH-4 LOWER	8/24/2004	Total PCBs	1190	1.19	110.19
SH-5 LOWER	8/25/2004	Total PCBs	1230	1.23	299.27
SH-6 UPPER	8/25/2004	Total PCBs	79	0.079	7.31
SH-6 LOWER	8/25/2004	Total PCBs	25	0.025	4.11
SH-7 LOWER	8/25/2004	Total PCBs	19	0.019	1.29
SH-8 LOWER	8/25/2004	Total PCBs	23	0.023	1.46
SH-9 UPPER	8/25/2004	Total PCBs	19 U	0.019	NC
SH-9 LOWER	8/25/2004	Total PCBs	19	0.019	1.26
		Shoreline	Locations		
SL-01	8/29/2011	Total PCBs	5900	5.9	NC
SL-02	8/29/2011	Total PCBs	790	0.79	NC
SL-03		Total PCBs	650	0.65	NC
SL-04		Total PCBs	280	0.28	NC
SL-05		Total PCBs	31	0.031	NC
SL-06		Total PCBs	103	0.103	NC



#### PCB CONCENTRATIONS IN SOIL AND SEDIMENT 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Analyte	Result (μg/kg Dry Weight)	mg/kg Dry Weight	mg/Kg OC			
	Uplands/HCIM Locations							
A3-08		Aroclor 1254	230	0.23	NC			
H2		Aroclor 1254	24	0.024	NC			
B7		Aroclor 1254	60	0.06 U	NC			
A1		Aroclor 1254	50	0.05 U	NC			

#### <u>Notes</u>

1. Data qualifiers are as follows:

U = not detected at reporting limit presented

2. Sample depths defined as follows:

Surface = 0 to 10 centimeters

Deep = 2 to 3 feet bgs

Lower = 0 to 10 centimeters

Upper = 5 to 26 centimeters

 $\frac{Abbreviations}{\mu g/kg = micrograms per kilogram} \\ mg/kg = milligrams per kilogram$ 

OC = organic carbon

NC = not calculated

PCBs = polychlorinated biphenyls



### BENZYL ALCOHOL CONCENTRATION IN SOIL 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Sample ID	Date	Method Group	Analyte	Concentration
RP-13	0087690050-RP-13	10/13/2011	PAHs	Benzyl Alcohol	4.6 U
RP-01	0087690050-RP-01	10/12/2011	PAHs	Benzyl Alcohol	77
RP-02	0087690050-RP-02	10/12/2011	PAHs	Benzyl Alcohol	36
RP-03	0087690050-RP-03	10/13/2011	PAHs	Benzyl Alcohol	87
RP-04	0087690050-RP-04	10/12/2011	PAHs	Benzyl Alcohol	4.7 U
RP-05	0087690050-RP-05	10/12/2011	PAHs	Benzyl Alcohol	4.8 U
RP-06	0087690050-RP-06	10/12/2011	PAHs	Benzyl Alcohol	4.8 U
RP-07	0087690050-RP-07	10/12/2011	PAHs	Benzyl Alcohol	4.8 U
RP-08	0087690050-RP-08	10/12/2011	PAHs	Benzyl Alcohol	4.8 U
RP-09	0087690050-RP-09	10/12/2011	PAHs	Benzyl Alcohol	4.8 U
RP-10	0087690050-RP-10	10/12/2011	PAHs	Benzyl Alcohol	4.7 U
RP-11	0087690050-RP-11	10/13/2011	PAHs	Benzyl Alcohol	4.7 U
RP-12	0087690050-RP-12	10/13/2011	SVOCs	Benzyl Alcohol	66
RP-14	0087690050-RP-14	10/14/2011	PAHs	Benzyl Alcohol	4.9 U
RP-15	0087690050-RP-15	10/13/2011	PAHs	Benzyl Alcohol	32
RP-15	0087690050-RP-15	10/13/2011	SVOCs	Benzyl Alcohol	42
RP-16	0087690050-RP-16	10/14/2011	PAHs	Benzyl Alcohol	44
RP-17	0087690050-RP-17	10/13/2011	PAHs	Benzyl Alcohol	110
RP-18	0087690050-RP-18	10/13/2011	PAHs	Benzyl Alcohol	4.9 U
RP-19	0087690050-RP-19	2/13/2012	PAHs	Benzyl Alcohol	24
RP-20	0087690050-RP-20	2/13/2012	PAHs	Benzyl Alcohol	150
RP-21	0087690050-RP-21	10/12/2011	PAHs	Benzyl Alcohol	4.7 U
RP-22	0087690050-RP-22	10/13/2011	PAHs	Benzyl Alcohol	60
RP-23	0087690050-RP-23	2/13/2012	PAHs	Benzyl Alcohol	95
RP-24	0087690050-RP-24	2/13/2012	PAHs	Benzyl Alcohol	200
RP-25	0087690050-RP-25	2/13/2012	PAHs	Benzyl Alcohol	130
RP-26	0087690050-RP-26	10/14/2011	PAHs	Benzyl Alcohol	5 U
RP-27	0087690050-RP-27	2/13/2012	PAHs	Benzyl Alcohol	67

- 1. All units in μg/kg (micrograms per kilogram).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented

### **Abbreviations**

PAHs = polycyclic aromatic hydrocarbons SVOCs = semivolatile organic compounds



### PENTACHLOROPHENOL CONCENTRATIONS IN SOIL<sup>1</sup>

Former Rhone-Poulenc Site Tukwila, Washington

Sample ID	Date	Analyte	Concentration
0087690050-RP-01		Pentachlorophenol	0.024
0087690050-RP-02		Pentachlorophenol	0.023
0087690050-RP-03		Pentachlorophenol	0.024
0087690050-RP-04	10/12/2011	Pentachlorophenol	0.024
0087690050-RP-05	10/12/2011	Pentachlorophenol	0.015
0087690050-RP-06	10/12/2011	Pentachlorophenol	0.024
0087690050-RP-07	10/12/2011	Pentachlorophenol	0.024
0087690050-RP-08	10/12/2011	Pentachlorophenol	0.024
0087690050-RP-09	10/12/2011	Pentachlorophenol	0.024
0087690050-RP-10	10/12/2011	Pentachlorophenol	0.024
0087690050-RP-11	10/13/2011	Pentachlorophenol	0.024
0087690050-RP-12	10/13/2011	Pentachlorophenol	0.024
0087690050-RP-13	10/13/2011	Pentachlorophenol	0.023
0087690050-RP-14	10/14/2011	Pentachlorophenol	0.024
0087690050-RP-15	10/13/2011	Pentachlorophenol	0.023
0087690050-RP-16	10/14/2011	Pentachlorophenol	0.024
0087690050-RP-17	10/13/2011	Pentachlorophenol	0.024
0087690050-RP-18	10/13/2011	Pentachlorophenol	0.024
0087690050-RP-19	2/13/2012	Pentachlorophenol	0.024
0087690050-RP-20	2/13/2012	Pentachlorophenol	0.024
0087690050-RP-21	10/12/2011	Pentachlorophenol	0.023
0087690050-RP-22	10/13/2011	Pentachlorophenol	0.024
0087690050-RP-23	2/13/2012	Pentachlorophenol	0.024
0087690050-RP-24	2/13/2012	Pentachlorophenol	0.025
0087690050-RP-25	2/13/2012	Pentachlorophenol	0.024
0087690050-RP-26	10/14/2011	Pentachlorophenol	0.025
0087690050-RP-27	2/13/2012	Pentachlorophenol	0.024
A01-01-01			0.61
A01-04-01			0.9
A01-06-01			4.9
A02-01-01			0.2
A02-09-01			0.074
A02-10-01			0.063
A02-11-02			0.04
A04-01-06			0.13
A04-02-01			0.19
A04-03-02			0.46
A04-04-03			0.055
A04-09-01			4.8

#### **Notes**

1. All units in mg/kg (milligrams per kilogram).



## ARSENIC CONCENTRATIONS IN SOIL 1,2

Site	Event	Date	Analyte	Concentration
A1	1991 SA		Arsenic	6
A1-01	Round 1		Arsenic	7.6
A1-02	Round 1		Arsenic	5
A1-03	Round 1		Arsenic	2.9
A1-04	Round 1		Arsenic	6
A1-05	Round 1		Arsenic	2.1
A1-06	Round 1		Arsenic	7.05
A1-07	Round 1		Arsenic	3.7
A10A201	Round 1		Arsenic	2
A10A202	Round 1		Arsenic	1.9
A10A203	Round 1		Arsenic	1.2
A10A204	Round 1		Arsenic	2.6
A10A601	Round 1		Arsenic	17.5
A10A602	Round 1		Arsenic	4.1
A10A603	Round 1	_	Arsenic	3.2
A10A604	Round 1		Arsenic	4.3
A10CR01	Round 1		Arsenic	5.6
A10CR02	Round 1		Arsenic	4.1
A10CR03	Round 1		Arsenic	4.9
A10CR04	Round 1		Arsenic	4.8
A10CS01	Round 1		Arsenic	2.8
A10CS02	Round 1		Arsenic	7.5
A10CS03	Round 1		Arsenic	52
A10CS04	Round 1		Arsenic	5.5
A10-MS	Round 1		Arsenic	3.6
A10MS02	Round 1		Arsenic	2.5
A10MS03	Round 1		Arsenic	61.4
A2	1991 SA		Arsenic	6 U
A2-01	Round 1		Arsenic	4.5
A2-02	Round 1		Arsenic	2.75
	Round 1		Arsenic	5
A2-04	Round 1		Arsenic	1.9
	Round 1		Arsenic	4.8
	Round 1		Arsenic	2.1
	Round 1		Arsenic	4.4
	Round 1		Arsenic	1.9
	Round 1		Arsenic	5.3
	Round 1		Arsenic	4.1
	Round 1		Arsenic	3.3
	Round 1		Arsenic	1.2
	Round 1		Arsenic	5.2
	Round 1		Arsenic	4.4
	1991 SA		Arsenic	5 U
	Round 1		Arsenic	3.2
A3-02	Round 1		Arsenic	2.8



## ARSENIC CONCENTRATIONS IN SOIL 1,2

Site	Event	Date	Analyte	Concentration
A3-03	Round 1		Arsenic	2.4
A3-04	Round 1		Arsenic	3.4
A3-05	Round 1		Arsenic	4.3
A3-06	Round 1		Arsenic	5.2
A3-07	Round 1		Arsenic	3.45
A4	1991 SA		Arsenic	8
A4-01	Round 1		Arsenic	2.9
A4-02	Round 1		Arsenic	1.6
A4-03	Round 1		Arsenic	6
A4-04	Round 1		Arsenic	1.6
A4-05	Round 1		Arsenic	1.6
A4-06	Round 1		Arsenic	6.8
A4-07	Round 1	1	Arsenic	2.9
A4-08	Round 1	1	Arsenic	3
	Round 1		Arsenic	3.1
	Round 1		Arsenic	2.2
	Round 1		Arsenic	3.1
	Round 1		Arsenic	2.6
	Round 1		Arsenic	2.6
	1991 SA		Arsenic	5 U
	1991 SA		Arsenic	6 U
	Round 1		Arsenic	4.3
	Round 1		Arsenic	4
	Round 1		Arsenic	3.8
	Round 1		Arsenic	0.5
	Round 1		Arsenic	6.4
	Round 1		Arsenic	2.8
	Round 1		Arsenic	1.6
	1991 SA		Arsenic	6
	Round 1		Arsenic	6.4
	Round 1		Arsenic	2.7
	Round 1		Arsenic	1.1
	Round 1		Arsenic	2.4
	Round 1		Arsenic	4.9
	Round 1	†	Arsenic	6.7
	Round 1	1	Arsenic	3.5
	1991 SA	1	Arsenic	8
	Round 1	1	Arsenic	6.1
	Round 1	1	Arsenic	6.1
	Round 1	1	Arsenic	3.8
	Round 1		Arsenic	5.9
	Round 1	1	Arsenic	5.2
	Round 1		Arsenic	5.2
	Round 1		Arsenic	1.3
	1991 SA		Arsenic	1.5 6 U
	Round 1		Arsenic	8.9
	Round 1	1	Arsenic	3.25
A0-UZ	INOUIIU I	<u> </u>	AISCIIIC	3.23



## ARSENIC CONCENTRATIONS IN SOIL 1,2

Site	Event	Date	Analyte	Concentration
A8-03	Round 1		Arsenic	15.4
A8-04	Round 1		Arsenic	4.8
A8-05	Round 1		Arsenic	24.7
A8-06	Round 1		Arsenic	2.6
A8-07	Round 1		Arsenic	4.6
A9	1991 SA		Arsenic	6 U
A9-01	Round 1		Arsenic	2.3
A9-02	Round 1		Arsenic	11.2
A9-03	Round 1		Arsenic	2.3
A9-04	Round 1		Arsenic	6.5
A9-05	Round 1		Arsenic	3.3
A9-06	Round 1		Arsenic	4.1
A9-07	Round 1		Arsenic	5
	Round 1		Arsenic	7.1
ABG-02	Round 1		Arsenic	2.8
ABG-03	Round 1		Arsenic	6.2
	Round 1		Arsenic	2.6
	Round 1		Arsenic	2.2
ABG-06			Arsenic	1.85
	Round 1		Arsenic	2.2
	1991 SA		Arsenic	7
	1991 SA		Arsenic	5 U
	1991 SA		Arsenic	6 U
	1991 SA		Arsenic	4 U
	1991 SA		Arsenic	6 U
	1991 SA		Arsenic	5 U
	1991 SA		Arsenic	11
	1991 SA		Arsenic	4 U
	1991 SA		Arsenic	5 U
	1991 SA		Arsenic	4 U
	1991 SA		Arsenic	7 U
	1991 SA		Arsenic	4 U
	1991 SA		Arsenic	7 U
	1991 SA		Arsenic	5 U
	1991 SA		Arsenic	7 U
	1991 SA		Arsenic	5 U
	1991 SA		Arsenic	7 U
	1991 SA		Arsenic	5 U
	1991 SA		Arsenic	7
	1991 SA		Arsenic	4 U
	1991 SA		Arsenic	7 U
	1991 SA		Arsenic	5 U
	1991 SA		Arsenic	6 U
	1991 SA		Arsenic	7 U
	1991 SA		Arsenic	9
	1991 SA		Arsenic	4 U
	1991 SA		Arsenic	6 U
	1991 SA		Arsenic	4 U



# ARSENIC CONCENTRATIONS IN SOIL 1,2

Site	Event	Date	Analyte	Concentration
G3	1991 SA		Arsenic	7
G4	1991 SA		Arsenic	4 U
G5	1991 SA		Arsenic	5 U
G6	1991 SA		Arsenic	5 U
G7	1991 SA		Arsenic	5 U
G8	1991 SA		Arsenic	5 U
G9	1991 SA		Arsenic	5 U
H1	1991 SA		Arsenic	6 U
H11	1991 SA		Arsenic	4 U
H2	1991 SA		Arsenic	5 U
H3	1991 SA		Arsenic	4 U
H4	1991 SA		Arsenic	6 U
H5	1991 SA		Arsenic	4 U
H6	1991 SA		Arsenic	5 U
	1991 SA		Arsenic	4 U
	1991 SA		Arsenic	7 U
	1991 SA		Arsenic	4 U
	AMEC Sediment and Shoreline Investigation	10/12/2011		9.4
	AMEC Sediment and Shoreline Investigation	10/12/2011		9.9
	AMEC Sediment and Shoreline Investigation	10/13/2011		10.4
	AMEC Sediment and Shoreline Investigation	10/12/2011		7.8
	AMEC Sediment and Shoreline Investigation	10/12/2011		10.8
	AMEC Sediment and Shoreline Investigation	10/12/2011		8.9
	AMEC Sediment and Shoreline Investigation	10/12/2011		9
	AMEC Sediment and Shoreline Investigation	10/12/2011		8.4
	AMEC Sediment and Shoreline Investigation	10/12/2011		5.8
	AMEC Sediment and Shoreline Investigation	10/12/2011		9.9
	AMEC Sediment and Shoreline Investigation	10/13/2011		4.9
	AMEC Sediment and Shoreline Investigation	10/13/2011		9.4
	AMEC Sediment and Shoreline Investigation	10/13/2011		4
	AMEC Sediment and Shoreline Investigation	10/14/2011	Arsenic	6.1
	AMEC Sediment and Shoreline Investigation	10/13/2011		7.4
	AMEC Sediment and Shoreline Investigation	10/14/2011	Arsenic	8.5
	AMEC Sediment and Shoreline Investigation	10/13/2011		9.1
	AMEC Sediment and Shoreline Investigation	10/13/2011		5
	AMEC Sediment and Shoreline Investigation	2/13/2012	Arsenic	7.6
	AMEC Sediment and Shoreline Investigation	2/13/2012		13
	AMEC Sediment and Shoreline Investigation	10/12/2011		8
	AMEC Sediment and Shoreline Investigation	10/13/2011		10
	AMEC Sediment and Shoreline Investigation	2/13/2012		9.9
	AMEC Sediment and Shoreline Investigation	2/13/2012		9
	AMEC Sediment and Shoreline Investigation	2/13/2012		8.9
	AMEC Sediment and Shoreline Investigation	10/14/2011		8.5
	AMEC Sediment and Shoreline Investigation	2/13/2012		9
	EPA Sediment Investigation	8/25/2004		20
	EPA Sediment Investigation	8/25/2004		20
	EPA Sediment Investigation	8/25/2004		9 U
	EPA Sediment Investigation	8/25/2004		10 U



# ARSENIC CONCENTRATIONS IN SOIL 1,2

Site	Event	Date	Analyte	Concentration
SB-12 LOWER	EPA Sediment Investigation	8/25/2004		9
	EPA Sediment Investigation	8/25/2004		10
	EPA Sediment Investigation	8/25/2004		11
	EPA Sediment Investigation	8/25/2004	Arsenic	11
	EPA Sediment Investigation	8/25/2004	Arsenic	20
	EPA Sediment Investigation	8/25/2004		20
	EPA Sediment Investigation	8/25/2004		20
	EPA Sediment Investigation	8/25/2004	Arsenic	20
	EPA Sediment Investigation	8/24/2004		20
	EPA Sediment Investigation	8/24/2004	Arsenic	20
	EPA Sediment Investigation	8/24/2004	Arsenic	20
	EPA Sediment Investigation	8/24/2004	Arsenic	20
	EPA Sediment Investigation	8/24/2004	Arsenic	10
	EPA Sediment Investigation	8/24/2004	Arsenic	20
SB-6 LOWER	EPA Sediment Investigation	8/24/2004	Arsenic	20
SB-6 UPPER	EPA Sediment Investigation	8/24/2004	Arsenic	20
SB-7 LOWER	EPA Sediment Investigation	8/25/2004		20
	EPA Sediment Investigation	8/25/2004	Arsenic	20
	EPA Sediment Investigation	8/25/2004	Arsenic	10
	EPA Sediment Investigation	8/25/2004	Arsenic	10
SH-1 LOWER	EPA Sediment Investigation	8/24/2004	Arsenic	8
	EPA Sediment Investigation	8/24/2004	Arsenic	10
SH-2 LOWER	EPA Sediment Investigation	8/24/2004	Arsenic	11
	EPA Sediment Investigation	8/24/2004	Arsenic	11
SH-3 LOWER	EPA Sediment Investigation	8/24/2004	Arsenic	7 U
SH-3 UPPER	EPA Sediment Investigation	8/24/2004	Arsenic	10
SH-4 LOWER	EPA Sediment Investigation	8/24/2004	Arsenic	11
SH-4 UPPER	EPA Sediment Investigation	8/24/2004	Arsenic	9
SH-5 LOWER	EPA Sediment Investigation	8/25/2004	Arsenic	6 U
SH-5 UPPER	EPA Sediment Investigation	8/25/2004	Arsenic	7
SH-6 LOWER	EPA Sediment Investigation	8/25/2004	Arsenic	7 U
SH-6 UPPER	EPA Sediment Investigation	8/25/2004	Arsenic	8
SH-7 LOWER	EPA Sediment Investigation	8/25/2004		8
	EPA Sediment Investigation	8/25/2004		9
	EPA Sediment Investigation	8/25/2004	Arsenic	9
SH-8 UPPER	EPA Sediment Investigation	8/25/2004		8
	EPA Sediment Investigation	8/25/2004	Arsenic	7
	EPA Sediment Investigation	8/25/2004	Arsenic	9
	AMEC Sediment and Shoreline Investigation	8/29/2011		4.4
	AMEC Sediment and Shoreline Investigation	8/29/2011		3.2
	AMEC Sediment and Shoreline Investigation	8/29/2011		4.2
	AMEC Sediment and Shoreline Investigation	8/29/2011		5.7
	AMEC Sediment and Shoreline Investigation	8/29/2011		8.7
	AMEC Sediment and Shoreline Investigation	8/29/2011		5.1
	AMEC Sediment and Shoreline Investigation	8/30/2011		2
	AMEC Sediment and Shoreline Investigation	8/30/2011		3.3
	AMEC Sediment and Shoreline Investigation	8/30/2011		6.6
SL-10	AMEC Sediment and Shoreline Investigation	9/8/2011	Arsenic	3.5



# ARSENIC CONCENTRATIONS IN SOIL 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Event	Date	Analyte	Concentration
SL-11	AMEC Sediment and Shoreline Investigation	9/7/2011	Arsenic	3.8
SL-12	AMEC Sediment and Shoreline Investigation	9/7/2011	Arsenic	3.4
SL-13	AMEC Sediment and Shoreline Investigation	9/7/2011	Arsenic	6.3
SL-14	AMEC Sediment and Shoreline Investigation	9/6/2011	Arsenic	4.2
SL-15	AMEC Sediment and Shoreline Investigation	9/6/2011	Arsenic	5.4

### **Notes**

- 1. All units in mg/kg (milligrams per kilogram).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented

#### **Abbreviation**

1991 SA = 1991 Site Assessment



# COPPER CONCENTRATIONS IN SOIL 1

Site	Event	Date	Analyte	Concentration
	1991 SA		Copper	23
	Round 1		Copper	196
A1-02	Round 1		Copper	603
A1-04	Round 1		Copper	6850
	Round 1		Copper	15.1
	Round 1		Copper	28.25
A1-07	Round 1		Copper	79.5
A10A201			Copper	491
A10A202	Round 1		Copper	164
A10A203	Round 1		Copper	162
A10A204			Copper	655
A10A601	Round 1		Copper	535
A10A602	Round 1		Copper	545
A10A603	Round 1		Copper	61.7
A10A604	Round 1		Copper	70.5
A10CR01	Round 1		Copper	314
A10CR02	Round 1		Copper	222
A10CR03	Round 1		Copper	2580
A10CR04	Round 1		Copper	610
A10CS01	Round 1		Copper	1410
A10CS02	Round 1		Copper	799
A10CS03			Copper	188
A10CS04			Copper	311
A10-MS			Copper	114
A10MS01	Round 1		Copper	2540
A10MS02	Round 1		Copper	91.5
A10MS03	Round 1		Copper	362
	1991 SA		Copper	35
A2-06	Round 1		Copper	563
A2-07	Round 1		Copper	78
A2-08	Round 1		Copper	62.6
	Round 1		Copper	97.4
A2-12	Round 1		Copper	452
	Round 1		Copper	103
	1991 SA		Copper	17
A3-02	Round 1		Copper	485
A3-04	Round 1		Copper	204
A3-05	Round 1		Copper	59.6
A4	1991 SA		Copper	33



# COPPER CONCENTRATIONS IN SOIL 1

Site	Event	Date	Analyte	Concentration
A4-03	Round 1		Copper	75
A4-06	Round 1		Copper	38.7
A4-07	Round 1		Copper	13.9
A4-08	Round 1		Copper	47.8
A4-10	Round 1		Copper	18.3
A4-11	Round 1		Copper	15.4
A4-12	Round 1		Copper	16.4
A4-13	Round 1		Copper	18.1
A4A	1991 SA		Copper	26
A5	1991 SA		Copper	23
A5-01	Round 1		Copper	114
A5-03	Round 1		Copper	49.6
A5-04	Round 1		Copper	749
A5-05	Round 1		Copper	270
A5-06	Round 1		Copper	303
A6	1991 SA		Copper	14
A6-01	Round 1		Copper	132
A6-03	Round 1		Copper	109
A6-04	Round 1		Copper	712
A6-05	Round 1		Copper	519
A6-07	Round 1		Copper	57.9
A7	1991 SA		Copper	19
A7-02	Round 1		Copper	269
A7-03	Round 1		Copper	177
A7-05	Round 1		Copper	200
A7-07	Round 1		Copper	210
A8	1991 SA		Copper	25
A8-01	Round 1		Copper	119
A8-03	Round 1		Copper	66.8
A8-04	Round 1		Copper	23.8
A8-05	Round 1		Copper	23.3
A8-06	Round 1		Copper	47
A8-07	Round 1		Copper	391
A9	1991 SA		Copper	26
A9-02	Round 1		Copper	1670
A9-04	Round 1		Copper	587
	Round 1		Copper	32.2
	Round 1		Copper	26.6
	Round 1	İ	Copper	22.3
	Round 1		Copper	17.4
	1991 SA		Copper	17
	1991 SA		Copper	21



# COPPER CONCENTRATIONS IN SOIL 1

Site	Event	Date	Analyte	Concentration
B12	1991 SA		Copper	21
B13	1991 SA		Copper	86
B14	1991 SA		Copper	34
B15	1991 SA		Copper	42
B1A	1991 SA		Copper	34
B2	1991 SA		Copper	135
B3	1991 SA		Copper	25
B4	1991 SA		Copper	22
B5	1991 SA		Copper	27
B6	1991 SA		Copper	2750
B7	1991 SA		Copper	22
B8	1991 SA		Copper	24
B9	1991 SA		Copper	23
C1	1991 SA		Copper	28
C2	1991 SA		Copper	23
C3	1991 SA		Copper	22
D1	1991 SA		Copper	24
D2	1991 SA		Copper	18
D4	1991 SA		Copper	27
E2	1991 SA		Copper	37
E3	1991 SA		Copper	30
F1	1991 SA		Copper	37
F2	1991 SA		Copper	31
G1	1991 SA		Copper	24
G10	1991 SA		Copper	25
G2	1991 SA		Copper	22
G3	1991 SA		Copper	22
G4	1991 SA		Copper	24
G5	1991 SA		Copper	30
G6	1991 SA		Copper	18
G7	1991 SA		Copper	50
G8	1991 SA		Copper	19
G9	1991 SA		Copper	14
H1	1991 SA		Copper	18
H11	1991 SA		Copper	19
H2	1991 SA		Copper	26
H3	1991 SA		Copper	19
H4	1991 SA		Copper	23
	1991 SA		Copper	1800
H6	1991 SA		Copper	36
	1991 SA		Copper	16
	1991 SA		Copper	23
	1991 SA		Copper	39
SL-01	AMEC Sediment and Shoreline Investigation	8/29/2011	Copper	2180
	AMEC Sediment and Shoreline Investigation		Copper	202
	AMEC Sediment and Shoreline Investigation	8/29/2011	Copper	51.7
	AMEC Sediment and Shoreline Investigation	8/29/2011		54.2



# COPPER CONCENTRATIONS IN SOIL 1

Former Rhone-Poulenc Site Tukwila, Washington

Site	Event	Date	Analyte	Concentration
SL-05	AMEC Sediment and Shoreline Investigation	8/29/2011	Copper	27.2
SL-06	AMEC Sediment and Shoreline Investigation	8/29/2011	Copper	77.1
SL-07	AMEC Sediment and Shoreline Investigation	8/30/2011	Copper	12.2
	AMEC Sediment and Shoreline Investigation	8/30/2011	Copper	352
	AMEC Sediment and Shoreline Investigation	8/30/2011	Copper	94.1
	AMEC Sediment and Shoreline Investigation	9/8/2011		29.6
	AMEC Sediment and Shoreline Investigation	9/7/2011	Copper	80
	AMEC Sediment and Shoreline Investigation	9/7/2011	Copper	20.9
	AMEC Sediment and Shoreline Investigation	9/7/2011	Copper	93.9
	AMEC Sediment and Shoreline Investigation	9/6/2011	Copper	107
SL-15	AMEC Sediment and Shoreline Investigation	9/6/2011	Copper	99.4

#### Notes

1. All units in mg/kg (milligrams per kilogram).

### **Abbreviation**

1991 SA = 1991 Site Assessment



# MERCURY CONCENTRATIONS IN SOIL 1

Site ID	Event	Compound	Concentration
A1-01	Round 1	Mercury	0.34
A1-02	Round 1	Mercury	0.29
A1-04	Round 1	Mercury	0.45
A10A201		Mercury	0.3
A10A202		Mercury	0.13
A10A203		Mercury	0.1
A10A204		Mercury	0.66
A10A601		Mercury	0.46
A10A602		Mercury	4.2
A10A603		Mercury	1
A10A604		Mercury	1.9
A10CR01		Mercury	0.31
A10CR02		Mercury	0.22
A10CR03		Mercury	0.46
A10CR04		Mercury	0.64
A10CS01		Mercury	0.39
A10CS02		Mercury	1.2
A10CS03		Mercury	0.26
A10CS04		Mercury	0.21
A10-MS		Mercury	0.12
A10MS01		Mercury	0.15
A10MS02		Mercury	0.73
A10MS03		Mercury	0.39
	Round 1	Mercury	0.19
	Round 1	Mercury	0.62
	Round 1	Mercury	0.19
	Round 1	Mercury	0.32
	Round 1	Mercury	0.15
	Round 1	Mercury	0.27
	Round 1	Mercury	0.4
	Round 1	Mercury	0.4
	Round 1	Mercury	0.29
	Round 1	Mercury	20.2
	Round 1	Mercury	268
	Round 1	Mercury	0.62
	Round 1	Mercury	1.3
	Round 1	Mercury	1.2
	Round 1	Mercury	0.13
	Round 1	Mercury	0.22
	Round 1	Mercury	0.13
	Round 1	Mercury	1.1
	Round 1	Mercury	6.4
	Round 1	Mercury	0.42
	Round 1	Mercury	1.1
A8-03	Round 1	Mercury	0.33



# MERCURY CONCENTRATIONS IN SOIL 1

Site ID	Event	Compound	Concentration
A8-04	Round 1	Mercury	0.13
A8-05	Round 1	Mercury	0.14
	Round 1	Mercury	0.28
	Round 1	Mercury	4.3
	Round 1	Mercury	0.23
	Round 1	Mercury	0.93999
	Round 1	Mercury	0.16
	Round 1	Mercury	0.12
	Round 2	Mercury	0.13
	Round 2	Mercury	0.4763
	Round 2	Mercury	6.9712
	Round 2	Mercury	4.8
	Round 2	Mercury	3.2
	Round 2	Mercury	3.1
	Round 2	Mercury	0.4
	Round 2	Mercury	0.34
	Round 2	Mercury	6.1
	Round 2	Mercury	4.4
	Round 2	Mercury	7
	Round 2	Mercury	0.89
	Round 2	Mercury	0.36
	Round 2	Mercury	1.8
	Round 2	Mercury	2.9
	Round 2	Mercury	1.2
	Round 2	Mercury	0.27
	Round 2	Mercury	11.2
	Round 2	Mercury	0.16
	Round 2	Mercury	2
	Round 2	Mercury	1.3
	Round 2	Mercury	3.2
	Round 2	Mercury	6.6
	Round 2	Mercury	1.5
	Round 2	Mercury	5
	Round 2	Mercury	0.53
	Round 2	Mercury	1.5
	AMEC Sediment and Shoreline Investigation	Mercury	0.35
	AMEC Sediment and Shoreline Investigation	Mercury	0.1
	AMEC Sediment and Shoreline Investigation	Mercury	0.67
	AMEC Sediment and Shoreline Investigation	Mercury	0.19
	AMEC Sediment and Shoreline Investigation	Mercury	0.1
	AMEC Sediment and Shoreline Investigation	Mercury	0.95
	AMEC Sediment and Shoreline Investigation	Mercury	83
	AMEC Sediment and Shoreline Investigation	Mercury	0.43
	AMEC Sediment and Shoreline Investigation	Mercury	0.13
SL-11	AMEC Sediment and Shoreline Investigation	Mercury	0.21



# MERCURY CONCENTRATIONS IN SOIL 1

Former Rhone-Poulenc Site Tukwila, Washington

Site ID	Event	Compound	Concentration
SL-12	AMEC Sediment and Shoreline Investigation	Mercury	0.19
SL-13	AMEC Sediment and Shoreline Investigation	Mercury	1.68
SL-14	AMEC Sediment and Shoreline Investigation	Mercury	1.96
SL-15	AMEC Sediment and Shoreline Investigation	Mercury	0.13

#### <u>Notes</u>

1. All units in mg/kg (milligrams per kilogram).



# **VANADIUM CONCENTRATIONS IN SOIL**

Sample ID	Top <sup>1</sup>	Bottom <sup>1</sup>	Parameter	Result <sup>2</sup>
A01-01-01	0.0	0.5	Vanadium, Total	50.1
A01-02-01	0.0	0.5	Vanadium, Total	77.6
A01-03-01	0.0	0.5	Vanadium, Total	47.6
A01-04-01	0.0	0.5	Vanadium, Total	47.0
A01-05-01	0.0	0.5	Vanadium, Total	33.8
A01-06-01	0.0	0.5	Vanadium, Total	46.1
A01-07-01	0.0	0.5	Vanadium, Total	64.5
A02-01-01	7.0	9.0	Vanadium, Total	32.2
A02-01-05	7.0	9.0	Vanadium, Total	53.2
A02-02-01	1.0	1.5	Vanadium, Total	51.0
A02-02-05	7.0	9.0	Vanadium, Total	55.2
A02-03-01	1.0	1.5	Vanadium, Total	32.2
A02-03-05	7.0	9.0	Vanadium, Total	46.1
A02-04-01	1.0	1.5	Vanadium, Total	31.6
A02-04-05	7.0	9.0	Vanadium, Total	42.6
A02-05-01	1.0	1.5	Vanadium, Total	50.4
A02-05-02	1.0	3.0	Vanadium, Total	38.8
A02-05-05	7.0	9.0	Vanadium, Total	38.6
A02-05-08	12.5	14.0	Vanadium, Total	55.5
A02-06-01	1.0	1.5	Vanadium, Total	35.7
A02-06-05	7.0	9.0	Vanadium, Total	38.1
A02-07-01	1.0	1.5	Vanadium, Total	74.5
A02-07-02	1.5	3.0	Vanadium, Total	95.0
A02-07-04	5.0	7.0	Vanadium, Total	52.9
A02-08-01	1.0	1.5	Vanadium, Total	47.8
A02-08-02	1.5	3.0	Vanadium, Total	67.9
A02-08-03	3.0	5.0	Vanadium, Total	39.6
A02-09-01	1.0	1.5	Vanadium, Total	53.3
A02-09-04	5.0	7.0	Vanadium, Total	66.2
A02-09-05	7.0	9.0	Vanadium, Total	57.7
A02-10-01	0.5	1.0	Vanadium, Total	59.1
A02-10-07	10.5	12.0	Vanadium, Total	47.4
A02-11-01	1.0	1.5	Vanadium, Total	34.5
A02-11-02	1.5	3.0	Vanadium, Total	35.5
A02-11-03	3.0	5.0	Vanadium, Total	33.2
A02-12-01	1.0	1.5	Vanadium, Total	35.1
A02-12-02	1.5	3.0	Vanadium, Total	33.0
A02-12-04	5.0	7.0	Vanadium, Total	35.5
A02-13-01	1.0	1.5	Vanadium, Total	36.0
A02-13-03	3.0	5.0	Vanadium, Total	34.7
A02-13-05	7.0	9.0	Vanadium, Total	31.8
A02-14-02	1.5	3.0	Vanadium, Total	38.1
A02-14-05	7.0	9.0	Vanadium, Total	55.8
A03-01-01	0.0	0.5	Vanadium, Total	36.0
A03-02-01	0.0	0.5	Vanadium, Total	62.1



# **VANADIUM CONCENTRATIONS IN SOIL**

Sample ID	Top <sup>1</sup>	Bottom <sup>1</sup>	Parameter	Result <sup>2</sup>
A03-03-01	0.0	0.5	Vanadium, Total	35.1
A03-04-01	0.0	0.5	Vanadium, Total	61.6
A03-05-01	0.0	0.5	Vanadium, Total	31.6
A03-06-01	0.0	0.5	Vanadium, Total	48.8
A03-07-01	0.0	0.5	Vanadium, Total	58.9
A04-01-01	1.0	1.5	Vanadium, Total	49.3
A04-01-05	7.0	9.0	Vanadium, Total	50.8
A04-01-06	9.0	11.0	Vanadium, Total	40.4
A04-02-06	8.5	10.5	Vanadium, Total	54.8
A04-03-01	1.0	1.5	Vanadium, Total	30.3
A04-03-02	1.5	3.0	Vanadium, Total	35.2
A04-03-06	9.0	11.0	Vanadium, Total	34.9
A04-04-01	1.0	1.5	Vanadium, Total	37.7
A04-04-03	3.0	5.0	Vanadium, Total	42.4
A04-04-06	9.0	11.0	Vanadium, Total	37.8
A04-05-01	1.0	1.5	Vanadium, Total	36.3
A04-05-05	7.0	9.0	Vanadium, Total	35.5
A04-05-06	9.0	11.0	Vanadium, Total	39.6
A04-06-01	2.0	4.0	Vanadium, Total	36.5
A04-06-06	10.0	12.0	Vanadium, Total	41.8
A04-07-01	1.5	2.0	Vanadium, Total	37.9
A04-07-05	7.5	9.5	Vanadium, Total	41.2
A04-07-06	10.5	12.5	Vanadium, Total	52.5
A04-08-01	1.5	2.0	Vanadium, Total	41.4
A04-08-05	7.5	9.5	Vanadium, Total	47.0
A04-09-01	1.0	1.5	Vanadium, Total	43.4
A04-09-05	6.5	8.5	Vanadium, Total	50.8
A04-10-01	1.0	1.5	Vanadium, Total	40.8
A04-10-05	7.0	9.0	Vanadium, Total	44.9
A04-11-01	0.5	2.5	Vanadium, Total	29.4
A04-11-04	6.5	8.5	Vanadium, Total	36.2
A04-12-01	0.5	1.0	Vanadium, Total	29.9
A04-12-05	6.5	8.5	Vanadium, Total	36.7
A04-13-01	1.5	2.0	Vanadium, Total	35.4
A04-13-05	7.5	9.5	Vanadium, Total	54.4
A05-01-01	0.5	1.0	Vanadium, Total	45.4
A05-02-01	0.0	0.5	Vanadium, Total	40.4
A05-03-01	0.0	0.5	Vanadium, Total	56.0
A05-04-01	0.0	0.5	Vanadium, Total	70.9
A05-05-01	0.0	0.5	Vanadium, Total	50.7
A05-06-01	0.5	1.0	Vanadium, Total	106.0
A05-07-01	0.5	1.0	Vanadium, Total	27.1
A06-01-01	0.0	0.5	Vanadium, Total	62.9
A06-02-01	0.0	0.5	Vanadium, Total	37.3
A06-03-01	0.0	0.5	Vanadium, Total	88.8



# **VANADIUM CONCENTRATIONS IN SOIL**

Sample ID	Top <sup>1</sup>	Bottom <sup>1</sup>	Parameter	Result <sup>2</sup>
A06-04-01	0.0	0.5	Vanadium, Total	41.9
A06-05-01	0.0	0.5	Vanadium, Total	62.9
A06-06-01	0.0	0.5	Vanadium, Total	44.8
A06-07-01	0.0	0.5	Vanadium, Total	65.2
A07-02-01	1.5	3.5	Vanadium, Total	28.9
A07-02-05	7.5	9.0	Vanadium, Total	38.3
A07-03-01	2.0	4.0	Vanadium, Total	32.3
A07-03-05	8.0	9.0	Vanadium, Total	34.3
A07-04-02	8.0	9.0	Vanadium, Total	38.7
A07-05-01	2.0	4.0	Vanadium, Total	51.7
A07-05-05	8.0	9.0	Vanadium, Total	185.0
A07-06-01	0.5	1.5	Vanadium, Total	38.9
A07-06-05	7.5	9.0	Vanadium, Total	27.6
A07-07-01	0.0	0.5	Vanadium, Total	186.0
A07-07-05	6.0	8.0	Vanadium, Total	47.5
A07-08-01	1.5	3.5	Vanadium, Total	30.4
A07-08-05	7.5	9.0	Vanadium, Total	33.3
A08-01-01	0.0	0.5	Vanadium, Total	70.7
A08-02-01	0.0	0.5	Vanadium, Total	43.8
A08-03-01	0.0	0.5	Vanadium, Total	48.5
A08-04-01	0.0	0.5	Vanadium, Total	55.4
A08-05-01	0.0	0.5	Vanadium, Total	46.1
A08-06-01	0.0	0.5	Vanadium, Total	46.2
A08-07-01	0.0	0.5	Vanadium, Total	87.8
A09-01-01	0.0	0.5	Vanadium, Total	51.3
A09-02-01	0.0	0.5	Vanadium, Total	57.4
A09-03-01	0.0	0.5	Vanadium, Total	39.6
A09-04-01	0.0	0.5	Vanadium, Total	70.9
A09-05-01	0.0	0.5	Vanadium, Total	53.0
A09-06-01	0.0	0.5	Vanadium, Total	43.7
A09-07-01	0.0	0.5	Vanadium, Total	37.2
A10-MS-04	0.5	1.0	Vanadium, Total	52.0
A10A20101	0.5	1.0	Vanadium, Total	53.9
A10A20201	0.5	1.0	Vanadium, Total	40.7
A10A20301	0.5	1.0	Vanadium, Total	36.4
A10A20401	0.5	1.0	Vanadium, Total	38.1
A10A60101	1.0	1.5	Vanadium, Total	36.2
A10A60201	1.0	1.5	Vanadium, Total	49.4
A10A60301	1.0	1.5	Vanadium, Total	47.5
A10A60401	1.0	1.5	Vanadium, Total	52.9
A10CR0101	1.0	1.5	Vanadium, Total	29.9
A10CR0201	1.0	1.5	Vanadium, Total	39.7
A10CR0301	1.0	1.5	Vanadium, Total	33.9
A10CR0401	1.0	1.5	Vanadium, Total	39.7
A10CS0101	1.0	1.5	Vanadium, Total	33.3



### **VANADIUM CONCENTRATIONS IN SOIL**

Former Rhone-Poulenc Site Tukwila, Washington

Sample ID	Top <sup>1</sup>	Bottom <sup>1</sup>	Parameter	Result <sup>2</sup>
A10CS0201	1.0	1.5	Vanadium, Total	48.9
A10CS0301	1.0	1.5	Vanadium, Total	33.9
A10CR0401	1.0	1.5	Vanadium, Total	39.7
A10CS0101	1.0	1.5	Vanadium, Total	33.3
A10CS0201	1.0	1.5	Vanadium, Total	48.9
A10CS0301	1.0	1.5	Vanadium, Total	43.4
A10CS0401	1.0	1.5	Vanadium, Total	46.7
A10MS0101	0.0	0.5	Vanadium, Total	40.3
A10MS0201	0.5	1.0	Vanadium, Total	84.8
A10MS0301	0.5	1.0	Vanadium, Total	57.3
ABG-01-01	1.0	1.5	Vanadium, Total	37.5
ABG-01-05	7.0	9.0	Vanadium, Total	53.2
ABG-02-01	1.0	1.5	Vanadium, Total	47.4
ABG-02-05	7.0	9.0	Vanadium, Total	54.2
ABG-03-01	0.5	1.0	Vanadium, Total	38.7
ABG-03-05	7.0	9.0	Vanadium, Total	56.9
ABG-04-01	1.0	1.5	Vanadium, Total	35.4
ABG-04-04	7.0	9.0	Vanadium, Total	45.2
ABG-05-01	1.0	1.5	Vanadium, Total	38.8
ABG-05-05	7.0	9.0	Vanadium, Total	47.4
ABG-06-01	1.0	1.5	Vanadium, Total	39.7
ABG-06-05	7.0	9.0	Vanadium, Total	65.7
ABG-07-01	1.0	1.5	Vanadium, Total	43.0
ABG-07-05	7.0	9.0	Vanadium, Total	59.0
SL-12	0.5	2	Vanadium, Total	42.7
SL-02	0.5	2	Vanadium, Total	43.4
SL-10	0.5	2	Vanadium, Total	44.2
SL-14	0.5	2	Vanadium, Total	44.8
SL-09	5	7	Vanadium, Total	49.2
SL-15	0.5	2	Vanadium, Total	49.7
SL-08	0.5	2	Vanadium, Total	49.7
SL-04	10	12	Vanadium, Total	49.8
SL-07	10	12	Vanadium, Total	50
SL-05	5	7	Vanadium, Total	50.7
SL-13	0.5	2	Vanadium, Total	50.9
SL-01	10	12	Vanadium, Total	51.9
SL-06	0.5	2	Vanadium, Total	52.6
SL-11	10	12	Vanadium, Total	53.3
SL-03	10	12	Vanadium, Total	56.4

#### Notes:

- 1. Sample intervals in feet below ground surface.
- 2. Results measured in mg/kg (milligrams per kilogram).



# TOLUENE CONCENTRATIONS IN GROUNDWATER 1,2

Site	Date	Event	Concentration
A2	1/1/1991	1991	1 U
A4	1/1/1991		1 U
DM2B	1/1/1991		4.7
G1	1/1/1991		1 U
G3	1/1/1991		1 U
G5	1/1/1991		35000
H10	1/1/1991		330000
AB4		2001 Geoprobe	1 U
AD1		2001 Geoprobe	1 U
AE8		2001 Geoprobe	1 U
AG3		2001 Geoprobe	1 U
AK2		2001 Geoprobe	1 U
RPPW-01		AMEC Sediment and Shoreline Investigation	1 U
RPPW-02		AMEC Sediment and Shoreline Investigation	0.2 U
RPPW-03		AMEC Sediment and Shoreline Investigation	0.2 U
SL-07		AMEC Sediment and Shoreline Investigation	0.3 U
SL-08		AMEC Sediment and Shoreline Investigation	0.5 U
SL-09		AMEC Sediment and Shoreline Investigation	1.8
SL-10		AMEC Sediment and Shoreline Investigation	17
SL-11		AMEC Sediment and Shoreline Investigation	10
SL-12		AMEC Sediment and Shoreline Investigation	440
SL-13		AMEC Sediment and Shoreline Investigation	3.5
SL-14		AMEC Sediment and Shoreline Investigation	61
SL-15		AMEC Sediment and Shoreline Investigation	1 U
SH-1		EPA Sediment Study	1 U
SH-2		EPA Sediment Study	1 U
SH-3		EPA Sediment Study	1 U
SH-4		EPA Sediment Study	1 U
SH-5		EPA Sediment Study	1 U
SH-6		EPA Sediment Study	1 U
SH-7		EPA Sediment Study	1 U
SH-8		EPA Sediment Study	1 U
SH-9		EPA Sediment Study	1 U
14		HCIM Geoprobe	180000
J3		HCIM Geoprobe	65000
K4		HCIM Geoprobe	320000
L3		HCIM Geoprobe	1800
M4		HCIM Geoprobe	300000
A1-26	1/1/1994		7
A4-1	1/1/1994		17000
A4-10	1/1/1994		46000
A4-13	1/1/1994		5.2
A4-14	1/1/1994		470000
A4-15	1/1/1994		3.3
A4-17		Round 1	4.1
A4-18		Round 1	2.2
A4-2	1/1/1994		510000
A4-23	1/1/1994		480000
A4-27	1/1/1994	Round 1	0.6



# TOLUENE CONCENTRATIONS IN GROUNDWATER $^{1,2}$

Site	Date	Event	Concentration
A4-28	1/1/1994	Round 1	17000
A4-29	1/1/1994	Round 1	1.4
A4-3	1/1/1994	Round 1	270000
A4-4	1/1/1994	Round 1	450000
A4-5	1/1/1994	Round 1	1600
A4-6	1/1/1994	Round 1	7900
A4-7	1/1/1994	Round 1	230000
A4-8	1/1/1994	Round 1	890
A5-19	1/1/1994	Round 1	7700
A5-20	1/1/1994	Round 1	0.8
A5-22	1/1/1994	Round 1	57
A5-24	1/1/1994	Round 1	94000
A5-25	1/1/1994		25
DM3B	1/1/1994	Round 1	3
MW-12	1/1/1994	Round 1	84000
DM-7	11/1/2000		1 U
MW-22	11/1/2000		1 U
MW-24	11/1/2000		1.5
MW-31	11/1/2000		2.5
MW-36	11/1/2000		1.6
MW-37	11/1/2000		1 U
MW-A9	11/1/2000		1 U
MW-34		Round 11	25
DM-4		Round 12b	1 U
B2		Round 15	23
DM-3A		Round 15	1 U
MW-17		Round 17	13000
H1	2/1/1994		1200
MW-13	2/1/1994		630
MW-14	2/1/1994		3400
MW-16	2/1/1994		1100
MW-19	2/1/1994		9400
C9		Round 21	0.5 U
A9	10/1/1997		13
B4	10/1/1997		21
B5	10/1/1997		810
B6	10/1/1997		770
H11	10/1/1997		1400000
MW-18	10/1/1997		410000
MW-20	10/1/1997		71
B1A		Round 55-63	0.25 U
DM-5		Round 55-63	0.25 U
DM-8		Round 55-63	0.25 U
EX-3		Round 55-63	7
MW-27		Round 55-63	0.25 U
MW-28		Round 55-63	68
MW-29		Round 55-63	0.25 U
MW-38		Round 55-63	0.25 U



# TOLUENE CONCENTRATIONS IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
MW-39	3/18/2014	Round 55-63	0.25 U
MW-40	3/18/2014	Round 55-63	0.25 U
MW-41	9/9/2013	Round 55-63	55
MW-42	3/18/2014	Round 55-63	0.25 U
MW-43	9/18/2012	Round 55-63	180
MW-44	9/18/2012	Round 55-63	340
MW-45	3/5/2013	Round 55-63	0.49
MW-46	3/14/2012	Round 55-63	0.33
MW-15	11/1/1999		250000
MW-23	11/1/1999	Round 6	430
MW-25	11/1/1999	Round 6	7200
DM-2A	2/1/2000	Round 7	18
H9	5/1/2000		15
H6	7/1/2000	Round 9	1 U
MW-26	7/1/2000	Round 9	130

### <u>Notes</u>

- 1. All units in µg/L (microgram per liter).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented



# BENZENE CONCENTRATION IN GROUNDWATER 1,2

Site ID	Date	Event	Compound	Concentration
A2	11/1/2001	Round 14	Benzene	2.1
A4	1/1/1991		Benzene	1 U
A4-1	1/1/1994		Benzene	1
A4-10	1/1/1994		Benzene	15
A4-11	1/1/1994	Round 1	Benzene	5.8
A4-13	1/1/1994	Round 1	Benzene	1.8
A4-14	1/1/1994	Round 1	Benzene	1.5
A4-16	1/1/1994	Round 1	Benzene	6.1
A4-3	1/1/1994	Round 1	Benzene	62
A9	1/1/1991	1991	Benzene	1 U
AB4	7/1/2001	2001 Geoprobe	Benzene	1 U
AD1	7/1/2001	2001 Geoprobe	Benzene	1 U
AE8	7/1/2001	2001 Geoprobe	Benzene	1 U
AG3	7/1/2001	2001 Geoprobe	Benzene	1 U
AK2	7/1/2001	2001 Geoprobe	Benzene	1 U
B1A	3/19/2014	Round 55-63	Benzene	0.25 U
B1B	1/1/1991	1991	Benzene	1 U
B2	1/1/1991	1991	Benzene	1 U
B4	7/1/2001	Round 12b	Benzene	0.2 U
B5	1/1/1991		Benzene	6.3
B6	2/1/1994	Round 2	Benzene	0.8
C9	12/1/2003		Benzene	0.5 U
DM2A	1/1/1991	1991	Benzene	1 U
DM2B	1/1/1991		Benzene	1 U
DM3A	1/1/1991		Benzene	1 U
DM3B	1/1/1991		Benzene	1 U
DM4	1/1/1991		Benzene	1 U
DM5		Round 55-63	Benzene	0.25 U
DM-7		Round 15	Benzene	3.3
DM-8		Round 55-63	Benzene	0.25 U
EX-3		Round 55-63	Benzene	0.25 U
G1	1/1/1991		Benzene	1 U
G3	1/1/1991		Benzene	1 U
G5	1/1/1991		Benzene	500 U
H1	11/1/2001		Benzene	0.2 U
H10	1/1/1994		Benzene	36
H11	1/1/1994		Benzene	230
H6	1/1/1991		Benzene	1 U
H9	7/1/2000		Benzene	1 U
MW-12		Round 15	Benzene	1 U
MW-14		Round 14	Benzene	0.3 U
MW-15	11/1/1999		Benzene	40
MW-16	7/1/2000		Benzene	1 U
MW-17		Round 55-63	Benzene	0.25 U
MW-18	11/1/1999		Benzene	85
MW-22	7/1/2000		Benzene	1 U
MW-23	11/1/2000		Benzene	2.3
MW-24	8/1/2001	Round 13	Benzene	0.2 U



# BENZENE CONCENTRATION IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site ID	Date	Event	Compound	Concentration
MW-25	11/1/1999	Round 6	Benzene	1.7
MW-26	7/1/2000	Round 9	Benzene	2.5
MW-27	9/11/2013	Round 55-63	Benzene	0.25 U
MW-28	9/18/2012	Round 55-63	Benzene	0.61
MW-29		Round 55-63	Benzene	0.25 U
MW-31	11/1/2000		Benzene	1 U
MW-34	7/1/2000	Round 9	Benzene	1 U
MW-36	11/1/2000	Round 10	Benzene	1 U
MW-37	5/1/2000		Benzene	8
MW-38		Round 55-63	Benzene	0.25 U
MW-39		Round 55-63	Benzene	0.25 U
MW-40	3/18/2014	Round 55-63	Benzene	0.25 U
MW-41	3/19/2014	Round 55-63	Benzene	0.72
MW-42		Round 55-63	Benzene	0.25 U
MW-43	9/18/2012	Round 55-63	Benzene	0.45
MW-44	9/18/2012	Round 55-63	Benzene	1.1
MW-45	3/19/2014	Round 55-63	Benzene	0.25 U
MW-46	3/19/2014	Round 55-63	Benzene	0.25 U
MW-A9	11/1/2000	Round 10	Benzene	1 U
RPPW-01	12/22/2011	AMEC Sediment and Shoreline Investigation	Benzene	1 U
RPPW-02	12/23/2011	AMEC Sediment and Shoreline Investigation	Benzene	0.2 U
RPPW-03		AMEC Sediment and Shoreline Investigation	Benzene	0.2 U
SH-1	8/31/2004	EPA Sediment Study	Benzene	1 U
SH-2		EPA Sediment Study	Benzene	1 U
SH-3	8/31/2004	EPA Sediment Study	Benzene	1 U
SH-4	8/31/2004	EPA Sediment Study	Benzene	1 U
SH-5		EPA Sediment Study	Benzene	1 U
SH-6	8/30/2004	EPA Sediment Study	Benzene	1 U
SH-7	8/30/2004	EPA Sediment Study	Benzene	1 U
SH-8	8/30/2004	EPA Sediment Study	Benzene	1 U
SH-9		EPA Sediment Study	Benzene	1 U
SL-07	9/1/2011	AMEC Sediment and Shoreline Investigation	Benzene	0.2 U
SL-08	8/31/2011	AMEC Sediment and Shoreline Investigation	Benzene	0.2 U
SL-09	9/2/2011	AMEC Sediment and Shoreline Investigation	Benzene	0.7
SL-10	9/9/2011	AMEC Sediment and Shoreline Investigation	Benzene	0.2
SL-11		AMEC Sediment and Shoreline Investigation	Benzene	0.1
SL-12	9/19/2011	AMEC Sediment and Shoreline Investigation	Benzene	1.3
SL-13		AMEC Sediment and Shoreline Investigation	Benzene	0.3
SL-14	9/14/2011	AMEC Sediment and Shoreline Investigation	Benzene	0.6
SL-15		AMEC Sediment and Shoreline Investigation	Benzene	0.2 U

#### <u>Notes</u>

- 1. All units in µg/L (microgram per liter).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented



# ETHYLBENZENE CONCENTRATIONS IN GROUNDWATER 1,2

Site	Date	Event	Concentration
A2	1/1/1994	Round 1	ND
A4	1/1/1994	Round 1	ND
A9	1/1/1994	Round 1	ND
B1A	3/19/2014	Round 55-63	0.25 U
B1B	1/1/1994	Round 1	ND
B2	1/1/1994	Round 1	ND
B4	1/1/1994	Round 1	ND
B5	1/1/1994	Round 1	ND
B6	1/1/1994	Round 1	ND
DM-2A	1/1/1994	Round 1	ND
DM-2B	1/1/1994	Round 1	ND
DM3A	1/1/1994	Round 1	ND
DM3B	1/1/1994	Round 1	ND
DM-4	1/1/1994	Round 1	ND
DM-5	9/10/2013	Round 55-63	0.25 U
DM-7	1/1/1994	Round 1	ND
DM-8	3/18/2014	Round 55-63	0.25 U
EX-3	3/19/2014	Round 55-63	0.25 U
G1	1/1/1994	Round 1	ND
G3	1/1/1994	Round 1	ND
H1	1/1/1994	Round 1	ND
H10	1/1/1994	Round 1	ND
H11	1/1/1994	Round 1	ND
H6	1/1/1994	Round 1	ND
H9	1/1/1994	Round 1	ND
MW-12	1/1/1994	Round 1	ND
MW-17	9/10/2013	Round 55-63	0.35
MW-27	9/11/2013	Round 55-63	0.25 U
MW-28	9/11/2013	Round 55-63	0.25 U
MW-29	9/12/2013	Round 55-63	0.25 U
MW-38R	3/18/2014	Round 55-63	0.25 U
MW-39		Round 55-63	0.25 U
MW-40	3/18/2014	Round 55-63	0.25 U
MW-41	3/19/2014	Round 55-63	0.25 U
MW-42		Round 55-63	0.25 U
MW-43	3/19/2014	Round 55-63	0.25 U
MW-44		Round 55-63	0.25 U
MW-45		Round 55-63	0.25 U
MW-46		Round 55-63	0.25 U
RPPW-1		AMEC Sediment and Shoreline Investigation	1 U
RPPW-2		AMEC Sediment and Shoreline Investigation	0.2 U
RPPW-3		AMEC Sediment and Shoreline Investigation	0.2 U
SH-1		EPA Sediment Study	1 U
SH-2		EPA Sediment Study	1 U
SH-3	8/31/2004	EPA Sediment Study	1 U
SH-4		EPA Sediment Study	1 U
SH-5		EPA Sediment Study	1 U
SH-6	8/30/2004	EPA Sediment Study	1 U



# ETHYLBENZENE CONCENTRATIONS IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
SH-7	8/30/2004	EPA Sediment Study	1 U
SH-8	8/30/2004	EPA Sediment Study	1 U
SH-9	8/30/2004	EPA Sediment Study	1 U
SL-07	9/2/2011	AMEC Sediment and Shoreline Investigation	0.1
SL-08	9/1/2011	AMEC Sediment and Shoreline Investigation	0.2 U
SL-09	9/2/2011	AMEC Sediment and Shoreline Investigation	0.4
SL-10		AMEC Sediment and Shoreline Investigation	0.2 U
SL-11	9/12/2011	AMEC Sediment and Shoreline Investigation	0.2 U
SL-12	9/13/2011	AMEC Sediment and Shoreline Investigation	0.2 U
SL-13	9/20/2011	AMEC Sediment and Shoreline Investigation	0.2 U
SL-14	9/13/2011	AMEC Sediment and Shoreline Investigation	0.2 U
SL-15	9/21/2011	AMEC Sediment and Shoreline Investigation	0.2 U

### **Notes**

- 1. All units in µg/L (microgram per liter).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented

### **Abbreviations**

ND = no data



# NAPTHALENE AND PENTACHLOROPHENOL CONCENTRATIONS IN GROUNDWATER $^{1,2,3}$

Former Rhone-Poulenc Site Tukwila, Washington

			Concentrat	tion
Site ID	Date	Event	Pentachlorophenol	Naphthalene
A2	1/1/1994		ND	ND
A4	1/1/1994		ND	ND
A9	1/1/1994		ND	ND
B1A	1/1/1994		ND	ND
B1B	1/1/1994	Round 1	ND	ND
B2	1/1/1994	Round 1	ND	ND
B4	1/1/1994	Round 1	ND	ND
B5	1/1/1994	Round 1	ND	ND
B6	1/1/1994		ND	2.0
C1	1/1/1994	Round 1	ND	ND
DM1A	1/1/1994		ND	ND
DM1B	1/1/1994		ND	ND
DM-2A	1/1/1994	Round 1	ND	ND
DM-2B	1/1/1994	Round 1	ND	ND
DM3A	1/1/1994		ND	ND
DM3B	1/1/1994		ND	ND
DM-4	1/1/1994		ND	ND
DM-5	1/1/1994	Round 1	ND	ND
DM-6	1/1/1994		ND	ND
DM-7	1/1/1994	Round 1	ND	ND
DM-8	1/1/1994	Round 1	ND	ND
E3	1/1/1994	Round 1	ND	ND
G1	1/1/1994	Round 1	ND	ND
G3	1/1/1994	Round 1	ND	ND
H1	1/1/1994	Round 1	ND	ND
H10	1/1/1994	Round 1	5.0	ND
H11	1/1/1994	Round 1	ND	ND
H6	1/1/1994	Round 1	ND	ND
H9	1/1/1994		ND	ND
MW-12	1/1/1994	Round 1	ND	ND
		Naphthalene		
SH-1	8/31/2004	EPA Sediment Investigation	5.0	U
SH-2	8/31/2004	EPA Sediment Investigation	5.0	U
SH-3	8/31/2004	EPA Sediment Investigation	5.0	U
SH-4	8/31/2004	EPA Sediment Investigation	5.0	U
SH-5		EPA Sediment Investigation	5.0	
SH-6		EPA Sediment Investigation	5.0	U
SH-7		EPA Sediment Investigation	5.0	
SH-8		EPA Sediment Investigation	5.0	
SH-9		EPA Sediment Investigation	5.0	
SL-07		AMEC Sediment and Shoreline Investigation	0.5	-
SL-08		AMEC Sediment and Shoreline Investigation	0.5	
SL-09		AMEC Sediment and Shoreline Investigation	0.5	-
SL-10		AMEC Sediment and Shoreline Investigation	0.5	U
SL-11		AMEC Sediment and Shoreline Investigation	0.5	
SL-12		AMEC Sediment and Shoreline Investigation	0.5	
SL-13		AMEC Sediment and Shoreline Investigation	0.5	
SL-14		AMEC Sediment and Shoreline Investigation	6.0	
SL-15		AMEC Sediment and Shoreline Investigation	0.5	
RPPW-01		AMEC Sediment and Shoreline Investigation	2.5	U
RPPW-02		AMEC Sediment and Shoreline Investigation	0.5	
RPPW-03	12/23/2011	AMEC Sediment and Shoreline Investigation	0.5	U

 $\frac{Notes}{1. \ All \ units \ in \ \mu g/L \ (microgram \ per \ liter).}$ 

2. Data qualifiers are as follows:

U = not detected at reporting limit presented

3. Round 1 results from RFI do not have sampling date or reporting limits associated with the results.

**Abbreviation** 

ND = no data



# ALUMINUM CONCENTRATIONS IN GROUNDWATER 1,2

Site	Date	Event	Concentration
A2		Round 1	11900
A4		Round 1	16000
A9		Round 1	40700
B1A	3/14/2012	Round 55-63	3200
B1B		Round 1	328
B2		Round 1	40300
B4		Round 1	4740
B5		Round 1	30300
B6		Round 1	19700
DM-2A		Round 1	3480
DM-2B		Round 1	205
DM-3A		Round 1	26500
DM-3B		Round 1	413
DM-4		Round 1	1800
DM-5	9/21/2012	Round 55-63	5470
DM-7		Round 1	249.5
DM-8		Round 55-63	160
EX-3	12/27/2013	Round 55-63	470
G1		Round 1	28900
G3		Round 1	120000
H1		Round 1	26800
H10		Round 1	4970
H11		Round 1	6310
H6		Round 1	29400
H9		Round 1	76000
MW-12		Round 1	3060
MW-17		Round 55-63	1610
MW-27		Round 55-63	550
MW-28		Round 55-63	980
MW-29		Round 55-63	190
MW-38		Round 55-63	390
MW-39		Round 55-63	920
MW-40		Round 55-63	700
MW-41		Round 55-63	570
MW-42		Round 55-63	4330
MW-43		Round 55-63	1480
MW-44		Round 55-63	610
MW-45		Round 55-63	4290
MW-46		Round 55-63	110
RPPW-01		AMEC Sediment and Shoreline Investigation	1080
RPPW-02		AMEC Sediment and Shoreline Investigation	1630
RPPW-03		AMEC Sediment and Shoreline Investigation	1460
SL-07		AMEC Sediment and Shoreline Investigation	10200
SL-08		AMEC Sediment and Shoreline Investigation	129000
SL-09		AMEC Sediment and Shoreline Investigation	17100
SL-10		AMEC Sediment and Shoreline Investigation	593000
SL-11		AMEC Sediment and Shoreline Investigation	88800
SL-12		AMEC Sediment and Shoreline Investigation	163000
SL-13	9/20/2011	AMEC Sediment and Shoreline Investigation	82900



# ALUMINUM CONCENTRATIONS IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
SL-14	9/20/2011	AMEC Sediment and Shoreline Investigation	880000
SL-15	9/21/2011	AMEC Sediment and Shoreline Investigation	321000

#### **Notes**

- 1. All units in µg/L (microgram per liter).
- 2. Round 1 results from RFI do not have sampling date or reporting limits associated with the results.



# LEAD CONCENTRATIONS IN GROUNDWATER 1,2

Site	Date	Event	Concentration
A2		HCIM Geoprobe	25
A2	1/1/1994		7.3
A4	1/1/1994		9.8
A9	1/1/1994		23.8
B1		HCIM Geoprobe	40
B1A		Round 55-63	4.4
B1B	1/1/1994		24
B2	1/1/1994	Round 1	174.5
В3		HCIM Geoprobe	20
B4	1/1/1994		3.4
B5		HCIM Geoprobe	122
B5	1/1/1994		17.4
В6	9/1/2000	HCIM Geoprobe	12
В6	1/1/1994		7.8
B7	9/1/2000	HCIM Geoprobe	22
C10	9/1/2000	HCIM Geoprobe	18
C2	9/1/2000	HCIM Geoprobe	7
C4	9/1/2000	HCIM Geoprobe	69
C8	9/1/2000	HCIM Geoprobe	14
C9	9/1/2000	HCIM Geoprobe	240
C9	12/1/2003	Round 22	1 U
D1	9/1/2000	HCIM Geoprobe	27
D11	9/1/2000	HCIM Geoprobe	30
D12		HCIM Geoprobe	5 U
D13		HCIM Geoprobe	16
D3		HCIM Geoprobe	70
DM-2A	2/1/2000		27
DM-2B	1/1/1991		3 U
DM-3A	1/1/1994		31.1
DM-3B	1/1/1994	Round 1	3.6
DM-4	1/1/1994		2
DM-5	9/21/2012	Round 55-63	4.3
DM-7	11/1/2000		1
DM-8		Round 55-63	0.3
E14		HCIM Geoprobe	5 U
E15		HCIM Geoprobe	5 U
E16		HCIM Geoprobe	280
E2		HCIM Geoprobe	27
E4		HCIM Geoprobe	47
EX-3		Round 55-63	0.4
F1		HCIM Geoprobe	32
F3		HCIM Geoprobe	48
G1	1/1/1994		34.7
G2		HCIM Geoprobe	32
G3	1/1/1994		29.7
G4		HCIM Geoprobe	27
G5	1/1/1991		2
H1	9/1/2000	HCIM Geoprobe	21



# LEAD CONCENTRATIONS IN GROUNDWATER 1,2

Site	Date	Event	Concentration
H1	1/1/1994	Round 1	7.4
H10	1/1/1991	1991	8
H11	2/2/2004	Round 15	6
H3	9/1/2000	HCIM Geoprobe	22
H6	1/1/1994	Round 1	9
H9	1/1/1994	Round 1	28.8
12		HCIM Geoprobe	32
14		HCIM Geoprobe	72
J1		HCIM Geoprobe	26
J3		HCIM Geoprobe	22
K2		HCIM Geoprobe	31
K4		HCIM Geoprobe	20
L1		HCIM Geoprobe	20
L3		HCIM Geoprobe	30
M2		HCIM Geoprobe	28
M4		HCIM Geoprobe	14
MW-12	1/1/1994		7.1
MW-14	11/1/2000		2
MW-15		Round 12	6
MW-16	2/1/2000		110
MW-17		Round 55-63	2.9
MW-18	11/1/2000		1 U
MW-22	11/1/2000		1 U
MW-23		Round 12	1 U
MW-24			6.1
MW-25	2/1/2000		19
MW-26		Round 11	6
MW-27		Round 55-63	5.4
MW-28		Round 55-63	6.5
MW-29		Round 55-63	0.6
MW-31	7/1/2000		7
MW-34	11/1/2000		1 U
MW-36	5/1/2000		23
MW-37		Round 12	3
MW-38		Round 55-63	0.6
MW-39		Round 55-63	0.5
MW-40		Round 55-63	2
MW-41		Round 55-63	5.6
MW-42		Round 55-63	1.4
MW-43		Round 55-63	2.2
MW-44		Round 55-63	10.4
MW-45		Round 55-63	2.5
MW-46		Round 55-63	0.2
N1		HCIM Geoprobe	26
N3	9/1/2000	HCIM Geoprobe	30



# LEAD CONCENTRATIONS IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
O2	9/1/2000	HCIM Geoprobe	49
P1	9/1/2000	HCIM Geoprobe	38
P3		HCIM Geoprobe	34
Q2	9/1/2000	HCIM Geoprobe	10
Q4	9/1/2000	HCIM Geoprobe	26
R1	9/1/2000	HCIM Geoprobe	5 U
R3	9/1/2000	HCIM Geoprobe	18
RPPW-01	12/22/2011	AMEC Sediment and Shoreline Investigation	1.2
RPPW-02	12/23/2011	AMEC Sediment and Shoreline Investigation	2.3
RPPW-03	12/23/2011	AMEC Sediment and Shoreline Investigation	3
SB-5	9/7/2004	EPA Sediment Study	20 U
SB-6	9/7/2004	EPA Sediment Study	20 U
SH-1	8/31/2004	EPA Sediment Study	40 U
SH-2	8/31/2004	EPA Sediment Study	40 U
SH-3	8/31/2004	EPA Sediment Study	40 U
SH-4	8/31/2004	EPA Sediment Study	40 U
SH-5	8/31/2004	EPA Sediment Study	40 U
SH-6	8/31/2004	EPA Sediment Study	40 U
SH-7	8/31/2004	EPA Sediment Study	40 U
SH-8	8/31/2004	EPA Sediment Study	40 U
SH-9	8/31/2004	EPA Sediment Study	40 U
SL-07	9/2/2011	AMEC Sediment and Shoreline Investigation	5.4
SL-08		AMEC Sediment and Shoreline Investigation	13
SL-09	9/2/2011	AMEC Sediment and Shoreline Investigation	5.1
SL-10	9/9/2011	AMEC Sediment and Shoreline Investigation	196
SL-11	9/12/2011	AMEC Sediment and Shoreline Investigation	24.5
SL-12		AMEC Sediment and Shoreline Investigation	51.2
SL-13		AMEC Sediment and Shoreline Investigation	12.8
SL-14	9/14/2011	AMEC Sediment and Shoreline Investigation	98.4
SL-15	9/21/2011	AMEC Sediment and Shoreline Investigation	361
T1		HCIM Geoprobe	16
V1		HCIM Geoprobe	5 U
X1		HCIM Geoprobe	5 U
Z1		HCIM Geoprobe	5 U

#### **Notes**

- 1. All units in µg/L (microgram per liter).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented

#### <u>Abbreviation</u>

HCIM = Hydraulic Control Interim Measure



# ARSENIC CONCENTRATIONS IN GROUNWATER 1,2

Site ID	Date	Event	Concentration
A2	9/1/2000	HCIM Geoprobe	50
A2	1/1/1994		43
A4	1/1/1994	Round 1	10.1
A9	1/1/1994	Round 1	13.6
AB4	7/1/2001	2001 Geoprobe	2
AD1	7/1/2001	2001 Geoprobe	2
AE8		2001 Geoprobe	6
AG3	7/1/2001	2001 Geoprobe	2
AK2		2001 Geoprobe	16
B1		HCIM Geoprobe	35
B1A		Round 55-63	2.5
B1B	1/1/1994		nd
B2	1/1/1994		13.6
B3		HCIM Geoprobe	64
B4	1/1/1994		2.4
B5		HCIM Geoprobe	180
B5	1/1/1994		12.6
B6		HCIM Geoprobe	100
B6	1/1/1994		5.6
B7		HCIM Geoprobe	109
C10		HCIM Geoprobe	13
C2		HCIM Geoprobe	77
C4		HCIM Geoprobe	200
C8		HCIM Geoprobe	200
C9		HCIM Geoprobe	160
C9	12/1/2003	•	2
D1		HCIM Geoprobe	68
D11		HCIM Geoprobe	15
D12		HCIM Geoprobe	9
D13		HCIM Geoprobe	8
D3		HCIM Geoprobe	180
DM2A	1/1/1994		26.1
DM2B	1/1/1994		15.2
DM-3A	11/1/2004		20
DM3B	1/1/1994		13.2
DM-4	1/1/1994		2.1
DM-5		Round 55-63	40.1
DM-7	11/1/2004		32
DM-8		Round 55-63	3
E14		HCIM Geoprobe	5
E15		HCIM Geoprobe	6
E16		HCIM Geoprobe	4
E2		HCIM Geoprobe	30
E4		HCIM Geoprobe	70
EX-3		Round 55-63	2
F1		HCIM Geoprobe	70
F3		HCIM Geoprobe	150
G1	1/1/1994		40.9



# ARSENIC CONCENTRATIONS IN GROUNWATER 1,2

Site ID	Date	Event	Concentration
G2	9/1/2000	HCIM Geoprobe	180
G3	1/1/1994		56.5
G4	9/1/2000	HCIM Geoprobe	64
G5	1/1/1991		24
H1	9/1/2000	HCIM Geoprobe	118
H1	1/1/1994	Round 1	6.1
H10	1/1/1994	Round 1	11.2
H11	1/1/1994	Round 1	56.4
H3	9/1/2000	HCIM Geoprobe	150
H6	1/1/1994		26.3
H9	1/1/1994	Round 1	68.9
12	9/1/2000	HCIM Geoprobe	90
14	9/1/2000	HCIM Geoprobe	72
J1	9/1/2000	HCIM Geoprobe	107
J3	9/1/2000	HCIM Geoprobe	58
K2	9/1/2000	HCIM Geoprobe	127
K4	9/1/2000	HCIM Geoprobe	40
L1	9/1/2000	HCIM Geoprobe	110
L3	9/1/2000	HCIM Geoprobe	86
M2	9/1/2000	HCIM Geoprobe	78
M4	9/1/2000	HCIM Geoprobe	90
MW-12	1/1/1994	Round 1	24.5
MW-14	5/1/2001	Round 12	60
MW-15	5/1/2001	Round 12	15
MW-16	11/1/1999	Round 6	51
MW-17	9/20/2012	Round 55-63	8
MW-18	2/2/2004	Round 15	16
MW-22	11/1/1999		66
MW-23	2/1/2000		5.4
MW-24	11/1/1999		24
MW-25	2/1/2000		99
MW-26	11/1/1999		9.1
MW-27		Round 55-63	2
MW-28		Round 55-63	4.8
MW-29		Round 55-63	23.4
MW-31	7/1/2000		38
MW-34	11/1/1999		27
MW-36	5/1/2000		122
MW-37	7/1/2000		26
MW-38		Round 55-63	6.5
MW-39		Round 55-63	2.5
MW-40		Round 55-63	8
MW-41		Round 55-63	9.8
MW-42		Round 55-63	3.7
MW-43		Round 55-63	21.4
MW-44		Round 55-63	16
MW-45		Round 55-63	3
MW-46	3/19/2014	Round 55-63	2



# ARSENIC CONCENTRATIONS IN GROUNWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site ID	Date	Event	Concentration
N1	9/1/2000	HCIM Geoprobe	110
N3	9/1/2000	HCIM Geoprobe	90
O2	9/1/2000	HCIM Geoprobe	200
P1	9/1/2000	HCIM Geoprobe	102
P3	9/1/2000	HCIM Geoprobe	52
Q2	9/1/2000	HCIM Geoprobe	37
Q4	9/1/2000	HCIM Geoprobe	110
R1	9/1/2000	HCIM Geoprobe	7
R3	9/1/2000	HCIM Geoprobe	210
RPPW-01	12/22/2011	AMEC Sediment and Shoreline Investigation	4.6
RPPW-02	12/22/2011	AMEC Sediment and Shoreline Investigation	2.3
RPPW-03	12/23/2011	AMEC Sediment and Shoreline Investigation	4
SH-1	8/30/2004	EPA Sediment Study	100 U
SH-2	8/30/2004	EPA Sediment Study	100 U
SH-3	8/30/2004	EPA Sediment Study	100 U
SH-4	8/30/2004	EPA Sediment Study	100 U
SH-5	8/30/2004	EPA Sediment Study	100 U
SH-6	8/30/2004	EPA Sediment Study	100 U
SH-7	8/30/2004	EPA Sediment Study	100 U
SH-8	8/30/2004	EPA Sediment Study	100 U
SH-9	8/30/2004	EPA Sediment Study	100 U
SB-5	9/7/2004	EPA Sediment Study	50 U
SB-6		EPA Sediment Study	50 U
SL-07	9/2/2011	AMEC Sediment and Shoreline Investigation	42.2
SL-08	9/1/2011	AMEC Sediment and Shoreline Investigation	17.3
SL-09	9/2/2011	AMEC Sediment and Shoreline Investigation	6.3
SL-10	9/9/2011	AMEC Sediment and Shoreline Investigation	93
SL-11	9/12/2011	AMEC Sediment and Shoreline Investigation	40.3
SL-12	9/19/2011	AMEC Sediment and Shoreline Investigation	89
SL-13	9/20/2011	AMEC Sediment and Shoreline Investigation	24.9
SL-14	9/20/2011	AMEC Sediment and Shoreline Investigation	96
SL-15		AMEC Sediment and Shoreline Investigation	107
T1		HCIM Geoprobe	28
V1		HCIM Geoprobe	4
X1		HCIM Geoprobe	20
Z1	9/1/2000	HCIM Geoprobe	8

#### Notes

- 1. All units in µg/L (microgram per liter).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented

# **Abbreviation**

HCIM = Hydraulic Control Interim Measure



# COPPER CONCENTRATIONS IN GROUNDWATER 1,2

Site	Date	Event	Concentration
A2	9/1/2000	HCIM Geoprobe	230
A2	1/1/1994		37.5
A4	1/1/1994	Round 1	50
A9	1/1/1994	Round 1	119
AB4		2001 Geoprobe	8
AD1		2001 Geoprobe	8
AE8	7/1/2001	2001 Geoprobe	31
AG3	7/1/2001	2001 Geoprobe	2
AK2	7/1/2001	2001 Geoprobe	19
B1	9/1/2000	HCIM Geoprobe	380
B1A	3/14/2012	Round 55-63	47
B1B	1/1/1994	Round 1	22.5
B2	1/1/1994	Round 1	4290
B3	9/1/2000	HCIM Geoprobe	300
B4	11/1/2004	Round 14	18
B5	9/1/2000	HCIM Geoprobe	710
B5	1/1/1994	Round 1	96.9
B6	1/1/1994		304
B6	9/1/2000	HCIM Geoprobe	170
B7		HCIM Geoprobe	150
C10		HCIM Geoprobe	50
C2	9/1/2000	HCIM Geoprobe	220
C4	9/1/2000	HCIM Geoprobe	940
C8	9/1/2000	HCIM Geoprobe	260
C9		HCIM Geoprobe	16300
C9	12/1/2003		2 U
D1		HCIM Geoprobe	410
D11		HCIM Geoprobe	70
D12		HCIM Geoprobe	80
D13		HCIM Geoprobe	50
D3		HCIM Geoprobe	1210
DM-2A	2/1/2000		210
DM2B	1/1/1994		73
DM-3A	1/1/1994		94.4
DM3B	1/1/1994		19
DM-4	1/1/1994		11.3
DM-5		Round 55-63	54
DM-7	5/1/2001	Round 12	14
DM-8		Round 55-63	2
E14		HCIM Geoprobe	30
E15		HCIM Geoprobe	30
E16		HCIM Geoprobe	10 U
E4		HCIM Geoprobe	550
EX-3		Round 55-63	7
F1		HCIM Geoprobe	380
F3		HCIM Geoprobe	590
G1	1/1/1994		113
G2	9/1/2000	HCIM Geoprobe	343



# COPPER CONCENTRATIONS IN GROUNDWATER $^{1,2}$

Site	Date	Event	Concentration
G3	1/1/1994	Round 1	224
G4	9/1/2000	HCIM Geoprobe	320
G5	1/1/1991	1991	2 U
H1	9/1/2000	HCIM Geoprobe	277
H1	1/1/1994		39.9
H10	1/1/1991	1991	96
H11	2/2/2004	Round 15	44
H3	9/1/2000	HCIM Geoprobe	890
H6	1/1/1994		179
H9	1/1/1994		306
12	9/1/2000	HCIM Geoprobe	384
14	9/1/2000	HCIM Geoprobe	430
J1	9/1/2000	HCIM Geoprobe	203
J3	9/1/2000	HCIM Geoprobe	510
K2	9/1/2000	HCIM Geoprobe	250
K4		HCIM Geoprobe	700
L1	9/1/2000	HCIM Geoprobe	560
L3		HCIM Geoprobe	560
M2	9/1/2000	HCIM Geoprobe	283
M4		HCIM Geoprobe	310
MW-12	1/1/1994		84.1
MW-14		Round 15	28
MW-15	11/1/2000		56
MW-16	11/1/1999		210
MW-17		Round 55-63	42
MW-18	11/1/2000		12
MW-22		Round 12	4
MW-23		Round 12	24
MW-24	11/1/1999		210
MW-25	2/1/2000		150
MW-26	11/1/2000		49
MW-27		Round 55-63	131
MW-28		Round 55-63	67
MW-29		Round 55-63	13
MW-31	11/1/1999		35
MW-34		Round 12	8
MW-36	7/1/2000		146
MW-37	11/1/2004		43
MW-38		Round 55-63	13
MW-39		Round 55-63	11
MW-40		Round 55-63	14
MW-41		Round 55-63	56
MW-42		Round 55-63	17
MW-43 MW-44		Round 55-63	61 122
MW-45		Round 55-63	
MW-46		Round 55-63 Round 55-63	18 5
N1		HCIM Geoprobe	200
N3		HCIM Geoprobe	560
INO	9/ 1/ZUUU	II IOINI GEOPIODE	000



# COPPER CONCENTRATIONS IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
O2	9/1/2000	HCIM Geoprobe	410
P1		HCIM Geoprobe	320
P3	9/1/2000	HCIM Geoprobe	710
Q2	9/1/2000	HCIM Geoprobe	180
Q4	9/1/2000	HCIM Geoprobe	650
R1	9/1/2000	HCIM Geoprobe	40
R3		HCIM Geoprobe	430
RPPW-01	12/22/2011	AMEC Sediment and Shoreline Investigation	8
RPPW-02		AMEC Sediment and Shoreline Investigation	5
RPPW-03	12/23/2011	AMEC Sediment and Shoreline Investigation	5
SH-1	8/31/2004	EPA Sediment Study	8
SH-2	8/31/2004	EPA Sediment Study	14
SH-3	8/31/2004	EPA Sediment Study	4 U
SH-4	8/31/2004	EPA Sediment Study	9
SH-5		EPA Sediment Study	4 U
SH-6	8/30/2004	EPA Sediment Study	6
SH-7	8/30/2004	EPA Sediment Study	5
SH-8	8/30/2004	EPA Sediment Study	4 U
SH-9	8/30/2004	EPA Sediment Study	5
SB-5	9/7/2004	EPA Sediment Study	194
SB-6	9/7/2004	EPA Sediment Study	15
SL-07	9/2/2011	AMEC Sediment and Shoreline Investigation	103
SL-08		AMEC Sediment and Shoreline Investigation	121
SL-09		AMEC Sediment and Shoreline Investigation	57
SL-10		AMEC Sediment and Shoreline Investigation	1590
SL-11		AMEC Sediment and Shoreline Investigation	255
SL-12		AMEC Sediment and Shoreline Investigation	870
SL-13		AMEC Sediment and Shoreline Investigation	182
SL-14		AMEC Sediment and Shoreline Investigation	2740
SL-15		AMEC Sediment and Shoreline Investigation	1880
T1		HCIM Geoprobe	340
V1		HCIM Geoprobe	10 U
X1		HCIM Geoprobe	20
Z1	9/1/2000	HCIM Geoprobe	10 U

# **Notes**

- 1. All units in µg/L (microgram per liter).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented

### **Abbreviation**

HCIM = Hydraulic Control Interim Measure



# CADMIUM CONCENTRATIONS IN GROUNDWATER $^{1,2,3}$

A4 R	Round 1	
		ND
	Round 1	ND
A9 R	Round 1	ND
B1A 3/19/2014 R		2 U
	Round 1	ND
	Round 1	ND
B4 R	Round 1	ND
	Round 1	ND
DM-5 9/10/2013 R		2 U
	Round 1	ND ND
	Round 1	ND
DM-8 3/18/2014 R		2 U
	Round 1	ND ND
EX-3 3/19/2014 R		2 U
	Round 1	ND ND
	Round 1	ND
	Round 1	ND
l <del></del>	Round 1	ND
	Round 1	ND ND
	Round 1	ND
l	Round 1	ND
	Round 1	ND
MW-17 9/10/2013 R		2 U
MW-27 9/11/2013 R		2 U
MW-28 9/11/2013 R		10 U
MW-29 9/12/2013 R		2 U
MW-38 3/18/2014 R		2 U
MW-39 3/18/2014 R		2 U
MW-40 3/18/2014 R		2 U
MW-41 3/19/2014 R		2 U
MW-42 3/18/2014 R		2 U
	Round 55-63	3
MW-44 3/19/2014 R		2 U
MW-45 3/19/2014 R		2 U
MW-46 3/19/2014 R		2 U
! <del></del>	AMEC Sediment and Shoreline Investigation	2 U
	AMEC Sediment and Shoreline Investigation	2 U
	AMEC Sediment and Shoreline Investigation	2 U
	EPA Sediment Study	2 U
	EPA Sediment Study	2 U
	EPA Sediment Study	4 U
	EPA Sediment Study	4 U
	EPA Sediment Study	4 U
	EPA Sediment Study	4 U
	EPA Sediment Study	4 U



# CADMIUM CONCENTRATIONS IN GROUNDWATER $^{1,2,3}$

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
SH-6	8/30/2004	EPA Sediment Study	4 U
SH-7		EPA Sediment Study	4 U
SH-8		EPA Sediment Study	4 U
SH-9		EPA Sediment Study	4 U
SL-07	9/2/2011	AMEC Sediment and Shoreline Investigation	2 U
SL-08	9/1/2011	AMEC Sediment and Shoreline Investigation	2 U
SL-09		AMEC Sediment and Shoreline Investigation	2 U
SL-10		AMEC Sediment and Shoreline Investigation	2
SL-11	9/12/2011	AMEC Sediment and Shoreline Investigation	2 U
SL-12		AMEC Sediment and Shoreline Investigation	2 U
SL-13	9/20/2011	AMEC Sediment and Shoreline Investigation	2 U
SL-14		AMEC Sediment and Shoreline Investigation	4
SL-15	9/21/2011	AMEC Sediment and Shoreline Investigation	6

#### <u>Notes</u>

- 1. All units in  $\mu$ g/L (microgram per liter).
- 2. Data qualifiers are as follows:
  - U = not detected at reporting limit presented
- 3. Round 1 results from RFI do not have sampling date or reporting limits associated with the results.

#### Abbreviation:

ND = no data



# CHROMIUM CONCENTRATIONS IN GROUNDWATER 1,2,3

Site	Date	Event	Concentration
A2		Round 1	17.8
A4		Round 1	17.8
A9		Round 1	41.6
B1A	3/19/2014	Round 55-63	5 U
B1B		Round 1	11.9
B2		Round 1	105.5
B4		Round 1	24.5
B5		Round 1	44.5
B6		Round 1	33.3
DM-2A		Round 1	148
DM-2B		Round 1	ND
DM-3A		Round 1	39.3
DM-3B		Round 1	ND
DM-4		Round 1	17.8
DM-5	9/10/2013	Round 55-63	234
DM-7		Round 1	12.3
DM-8	3/18/2014	Round 55-63	5 U
EX-3	3/5/2013	Round 55-63	19
G1		Round 1	32.7
G3		Round 1	135
H1		Round 1	30.7
H10		Round 1	12.3
H11		Round 1	88.9
H6		Round 1	98
H9		Round 1	154
MW-12		Round 1	18.3
MW-17		Round 55-63	53
MW-27		Round 55-63	5 U
MW-28		Round 55-63	30
MW-29		Round 55-63	5 U
MW-38		Round 55-63	8
MW-39		Round 55-63	11
MW-40		Round 55-63	5
MW-41		Round 55-63	51
MW-42		Round 55-63	13
MW-43		Round 55-63	276
MW-44		Round 55-63	46
MW-45		Round 55-63	14
MW-46		Round 55-63	5 U
RPPW-01		AMEC Sediment and Shoreline Investigation	30
RPPW-02		AMEC Sediment and Shoreline Investigation	5 U
RPPW-03		AMEC Sediment and Shoreline Investigation	5 U
SH-1		EPA Sediment Study	10 U
SH-2		EPA Sediment Study	10 U
SH-3		EPA Sediment Study	10 U
SH-4		EPA Sediment Study	10 U
SH-5		EPA Sediment Study	10 U
SH-6	8/30/2004	EPA Sediment Study	10 U



# **CHROMIUM CONCENTRATIONS IN GROUNDWATER 1,2,3**

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
SH-7	8/30/2004	EPA Sediment Study	10 U
SH-8	8/30/2004	EPA Sediment Study	10 U
SH-9	8/30/2004	EPA Sediment Study	10 U
SB-5	9/7/2004	EPA Sediment Study	5 U
SB-6		EPA Sediment Study	5 U
SL-07	9/2/2011	AMEC Sediment and Shoreline Investigation	24
SL-08	9/1/2011	AMEC Sediment and Shoreline Investigation	83
SL-09	9/2/2011	AMEC Sediment and Shoreline Investigation	54
SL-10		AMEC Sediment and Shoreline Investigation	2180
SL-11		AMEC Sediment and Shoreline Investigation	253
SL-12		AMEC Sediment and Shoreline Investigation	1300
SL-13		AMEC Sediment and Shoreline Investigation	258
SL-14		AMEC Sediment and Shoreline Investigation	2590
SL-15	9/21/2011	AMEC Sediment and Shoreline Investigation	530

#### Notes

- 1. All units in µg/L (microgram per liter).
- 2. Data qualifiers are as follows:
  - U = not detected at reporting limit presented
- 3. Round 1 results from RFI do not have sampling date or reporting limits associated with the results.

#### Abbreviation:

ND = no data



# ZINC CONCENTRATIONS IN GROUNDWATER $^{1,2,3}$

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
A2		Round 1	ND
A4		Round 1	ND
A9		Round 1	ND
B1A	9/21/2012	Round 55-63	80
B1B		Round 1	15.4
B2		Round 1	13.9
B4		Round 1	ND
B5		Round 1	ND
В6		Round 1	ND
DM-2A		Round 1	36
DM-2B		Round 1	ND
DM-3A		Round 1	ND
DM-3B		Round 1	ND
DM-4		Round 1	ND
DM-5		Round 1	20
DM-5	9/10/2013	Round 55-63	30
DM-7		Round 1	67.9
DM-8		Round 1	ND
DM-8	3/18/2014	Round 55-63	10 U
EX-3	12/27/2013	Round 55-63	10
G1		Round 1	65.5
G3		Round 1	104
H1		Round 1	18
H10		Round 1	11.6
H11		Round 1	10.9
H6		Round 1	19
H9		Round 1	80.7
MW-12		Round 1	15.2
MW-17		Round 55-63	30
MW-27		Round 55-63	190
MW-28		Round 55-63	20
MW-29		Round 55-63	10
MW-38		Round 55-63	10 U
MW-39		Round 55-63	10 U
MW-40		Round 55-63	10
MW-41		Round 55-63	10 U
MW-42		Round 55-63	10
MW-43		Round 55-63	30
MW-44		Round 55-63	10 U
MW-45		Round 55-63	40
MW-46		Round 55-63	20
RPPW-01		AMEC Sediment and Shoreline Investigation	10 U
RPPW-02		AMEC Sediment and Shoreline Investigation	10 U
RPPW-03		AMEC Sediment and Shoreline Investigation	10 U
SB-5		EPA Sediment Study	11
SB-6		EPA Sediment Study	15
SH-1		EPA Sediment Study	10 U
SH-2	8/31/2004	EPA Sediment Study	30



# ZINC CONCENTRATIONS IN GROUNDWATER 1,2,3

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
SH-3	8/31/2004	EPA Sediment Study	10 U
SH-4	8/31/2004	EPA Sediment Study	10 U
SH-5	8/30/2004	EPA Sediment Study	10 U
SH-6	8/30/2004	EPA Sediment Study	10 U
SH-7	8/30/2004	EPA Sediment Study	10 U
SH-8	8/30/2004	EPA Sediment Study	10 U
SH-9	8/30/2004	EPA Sediment Study	10 U
SL-07	9/2/2011	AMEC Sediment and Shoreline Investigation	160
SL-08	9/1/2011	AMEC Sediment and Shoreline Investigation	160
SL-09	9/2/2011	AMEC Sediment and Shoreline Investigation	60
SL-10	9/9/2011	AMEC Sediment and Shoreline Investigation	2000
SL-11	9/12/2011	AMEC Sediment and Shoreline Investigation	290
SL-12	9/19/2011	AMEC Sediment and Shoreline Investigation	700
SL-13	9/20/2011	AMEC Sediment and Shoreline Investigation	330
SL-14		AMEC Sediment and Shoreline Investigation	2770
SL-15	9/21/2011	AMEC Sediment and Shoreline Investigation	1270

#### **Notes**

- 1. All units in µg/L (microgram per liter).
- 2. Data qualifiers are as follows:
  - U = not detected at reporting limit presented
- 3. Round 1 results from RFI do not have sampling date or reporting limits associated with the results.

## **Abbreviation**

ND = no data



# MERCURY CONCENTRATION IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
A2	9/1/2000	HCIM Geoprobe	0.4
A2		Round 12b	0.1 U
A4		Round 12b	0.1 U
A9	1/1/1994		0.22
AB4		2001 Geoprobe	0.1 U
AD1		2001 Geoprobe	0.1 U
AE8		2001 Geoprobe	0.1 U
AG3		2001 Geoprobe	0.1 U
AK2		2001 Geoprobe	0.1 U
B1		HCIM Geoprobe	0.4
B1A		Round 55-63	0.1 U
B1B	1/1/1994		ND
B2	1/1/1994		4.7
B3		HCIM Geoprobe	0.6
B4		Round 12b	0.0 0.1 U
B5		HCIM Geoprobe	0.6
B5	11/1/1999		0.0 0.1 U
B6		HCIM Geoprobe	0.10
B6	11/1/1999		0.6 0.1 U
B7		HCIM Geoprobe	0.1 0
C10 C2		HCIM Geoprobe HCIM Geoprobe	0.2
C2 C4		HCIM Geoprobe	1.7
C8		HCIM Geoprobe	2.1
C9		HCIM Geoprobe	58
C9 D1	12/1/2003		0.1 U
		HCIM Geoprobe	0.3
D11 D12		HCIM Geoprobe	0.3 0.1 U
		HCIM Geoprobe	0.1 U
D13		HCIM Geoprobe	
D3		HCIM Geoprobe	0.2
DM-2A	2/1/2000		0.23
DM-2B	1/1/1994		ND 0.4.11
DM-3A		Round 12b	0.1 U
DM-3B	1/1/1994		ND 0.4.11
DM-4		Round 12b	0.1 U
DM-5		Round 55-63	0.1
DM-7	11/1/1999		0.1 U
DM-8		Round 55-63	0.1 U
E14		HCIM Geoprobe	0.1 U
E15		HCIM Geoprobe	0.1 U
E16		HCIM Geoprobe	0.1 U
E2		HCIM Geoprobe	0.3
E4		HCIM Geoprobe	0.4
EX-3		Round 55-63	0.1 U
F1		HCIM Geoprobe	0.4
F3		HCIM Geoprobe	0.6
G1	1/1/1994		ND
G2		HCIM Geoprobe	0.8
G3	1/1/1994		0.49
G4	9/1/2000	HCIM Geoprobe	0.3



## MERCURY CONCENTRATION IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration		
H1	9/1/2000	HCIM Geoprobe	1.3		
H1		Round 14	0.1 U		
H10	2/1/2000		0.35		
H11	11/1/1999		0.2 U		
H3		HCIM Geoprobe	2		
H6	1/1/1994		0.45		
H9	1/1/1994		0.87		
12		HCIM Geoprobe	0.2		
14		HCIM Geoprobe	2		
J1		HCIM Geoprobe	0.2		
J3		HCIM Geoprobe	0.3		
K2		HCIM Geoprobe	0.3		
K4		HCIM Geoprobe	2 U		
L1		HCIM Geoprobe	1.2		
L3		HCIM Geoprobe	0.5 U		
M2		HCIM Geoprobe	0.5		
M4		HCIM Geoprobe	0.1 U		
MW-12	11/1/1999		0.2 U		
MW-14	2/1/2000		0.45		
MW-15		Round 12	0.2		
MW-16	11/1/2000		0.1		
MW-17		Round 55-63	0.1 U		
MW-18		Round 12	0.1 U		
MW-22	11/1/2000		0.1 U		
MW-23	2/1/2000	Round 7	0.21		
MW-24	5/1/2000	Round 8	0.1		
MW-25	11/1/1999	Round 6	0.36		
MW-26	11/1/2004	Round 14	0.1 U		
MW-27	9/11/2013	Round 55-63	0.1 U		
MW-28	9/11/2013	Round 55-63	0.1 U		
MW-29	9/12/2013	Round 55-63	0.1 U		
MW-31	8/1/2004	Round 13	0.2		
MW-36	5/1/2000	Round 8	0.3		
MW-37	7/1/2000		0.1 U		
MW-38		Round 55-63	0.1 U		
MW-39		Round 55-63	0.1 U		
MW-40		Round 55-63	0.1 U		
MW-41		Round 55-63	0.1 U		
MW-42		Round 55-63	0.1 U		
MW-43		Round 55-63	0.1		
MW-44		Round 55-63	0.1		
MW-45		Round 55-63	0.1 U		
MW-46		Round 55-63	0.1 U		
N1		HCIM Geoprobe	0.4		
N3		HCIM Geoprobe	0.7		
O2		HCIM Geoprobe	0.4		
P1		HCIM Geoprobe	0.3		
P3		HCIM Geoprobe	0.2		
Q2	9/1/2000	HCIM Geoprobe	0.1		



## MERCURY CONCENTRATION IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
Q4		HCIM Geoprobe	0.1 U
R1	9/1/2000	HCIM Geoprobe	0.1 U
R3		HCIM Geoprobe	0.1 U
RPPW-01	12/22/2011	AMEC Sediment and Shoreline Investigation	0.1 U
RPPW-02	12/22/2011	AMEC Sediment and Shoreline Investigation	0.1 U
RPPW-02	12/23/2011	AMEC Sediment and Shoreline Investigation	0.1 U
SB-5	9/7/2004	EPA Sediment Study	0.1 U
SB-6	9/7/2004	EPA Sediment Study	0.1 U
SH-1		EPA Sediment Study	0.1 U
SH-2	8/31/2004	EPA Sediment Study	0.1 U
SH-3		EPA Sediment Study	0.1 U
SH-4		EPA Sediment Study	0.1 U
SH-5	8/31/2004	EPA Sediment Study	0.1 U
SH-6		EPA Sediment Study	0.1 U
SH-7		EPA Sediment Study	0.1 U
SH-8		EPA Sediment Study	0.1 U
SH-9		EPA Sediment Study	0.1 U
SL-07		AMEC Sediment and Shoreline Investigation	0.152
SL-08		AMEC Sediment and Shoreline Investigation	2.76
SL-09		AMEC Sediment and Shoreline Investigation	0.123
SL-10		AMEC Sediment and Shoreline Investigation	2.7
SL-11		AMEC Sediment and Shoreline Investigation	0.511
SL-12		AMEC Sediment and Shoreline Investigation	0.542
SL-13		AMEC Sediment and Shoreline Investigation	0.193
SL-14		AMEC Sediment and Shoreline Investigation	9.46
SL-15		AMEC Sediment and Shoreline Investigation	9.76
T1		HCIM Geoprobe	0.1 U
V1	9/1/2000	HCIM Geoprobe	0.1 U
X1		HCIM Geoprobe	0.1 U
Z1	9/1/2000	HCIM Geoprobe	0.1 U

## <u>Notes</u>

- 1. All units in µg/L (microgram per liter).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented

## Abbreviation:

ND = no data



# NICKEL CONCENTRATION IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
A2	1/1/1994	Round 1	24.9
A4	1/1/1994	Round 1	37.2
A9	1/1/1994	Round 1	48.7
AB4	7/1/2001	2001 Geoprobe	10 U
AD1	7/1/2001	2001 Geoprobe	10
AE8	7/1/2001	2001 Geoprobe	10
AG3		2001 Geoprobe	10
AK2		2001 Geoprobe	10 U
B1A		Round 55-63	60
B1B	1/1/1991		10 U
B2	1/1/1991	1991	4.7
B4	1/1/1991		10 U
B5	1/1/1994	Round 1	44.4
B6	1/1/1994	Round 1	26.6
C9	12/1/2003		10 U
DM2A	1/1/1991	1991	20
DM2B	1/1/1991		10 U
DM3A	1/1/1991	1991	10 U
DM-3A	1/1/1994	Round 1	64.3
DM3B	1/1/1991	1991	10 U
DM4	1/1/1991	1991	10 U
DM-5	9/21/2012	Round 55-63	10
DM-7	11/1/1999	Round 6	16
DM8	3/18/2014	Round 55-63	10 U
EX-3		Round 55-63	10 U
G1	1/1/1994		70.6
G3	1/1/1994		93.7
H1	1/1/1991		10 U
H10	11/1/2000		40
H11	1/1/1991		10 U
H6	1/1/1994		34.6
H9	1/1/1994		74.7
MW-12	1/1/1994		37.1
MW-14	11/1/2000		10 U
MW-15	11/1/2000		10 U
MW-16	11/1/1999		32
MW-17		Round 55-63	10 U
MW-18	11/1/2000		10 U
MW-22	11/1/2000		10 U
MW-23	11/1/2000		10 U
MW-24	11/1/1999		27
MW-25	11/1/2000		10 U
MW-26	11/1/2000		10 U
MW-27		Round 55-63	10
MW-28		Round 55-63	10 U
MW-29	9/12/2013	Round 55-63	10 U



# NICKEL CONCENTRATION IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site	Date	Event	Concentration
MW-31	7/1/2000	Round 9	10
MW-34	5/1/2004	Round 12	60
MW-36	11/1/2000	Round 10	10 U
MW-37	2/2/2004	Round 15	150
MW-38	3/18/2014	Round 55-63	10 U
MW-39	3/18/2014	Round 55-63	10 U
MW-40		Round 55-63	10 U
MW-41		Round 55-63	10 U
MW-42		Round 55-63	10 U
MW-43	9/10/2013	Round 55-63	60
MW-44		Round 55-63	20
MW-45		Round 55-63	10 U
MW-46		Round 55-63	10 U
RPPW-01	12/22/2011	AMEC Sediment and Shoreline Investigation	10 U
RPPW-02		AMEC Sediment and Shoreline Investigation	10 U
RPPW-03	12/23/2011	AMEC Sediment and Shoreline Investigation	10 U
SH-1	8/31/2004	EPA Sediment Study	20 U
SH-2	8/31/2004	EPA Sediment Study	20 U
SH-3	8/31/2004	EPA Sediment Study	20 U
SH-4		EPA Sediment Study	20 U
SH-5	8/30/2004	EPA Sediment Study	20 U
SH-6	8/30/2004	EPA Sediment Study	20 U
SH-7	8/30/2004	EPA Sediment Study	20 U
SH-8	8/30/2004	EPA Sediment Study	20 U
SH-9	8/30/2004	EPA Sediment Study	20 U
SB-5	9/7/2004	EPA Sediment Study	0.1 U
SB-6		EPA Sediment Study	0.1 U
SL-07	9/2/2011	AMEC Sediment and Shoreline Investigation	10 U
SL-08	9/1/2011	AMEC Sediment and Shoreline Investigation	10 U
SL-09		AMEC Sediment and Shoreline Investigation	20
SL-10	9/9/2011	AMEC Sediment and Shoreline Investigation	610
SL-11		AMEC Sediment and Shoreline Investigation	100
SL-12		AMEC Sediment and Shoreline Investigation	200
SL-13		AMEC Sediment and Shoreline Investigation	110
SL-14		AMEC Sediment and Shoreline Investigation	550
SL-15	9/21/2011	AMEC Sediment and Shoreline Investigation	340

## <u>Notes</u>

- 1. All units in µg/L (microgram per liter).
- 2. Data qualifiers are as follows:

U = not detected at reporting limit presented



# VANADIUM CONCENTRATIONS IN GROUNDWATER 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site ID	Date	Event	Concentration
AB4	7/1/2001	2001 Geoprobe	31
A2	1/1/1994	Round 1	134
A4	1/1/1994	Round 1	107
A9	1/1/1994	Round 1	161
AD1	7/1/2001	2001 Geoprobe	30
AE8	7/1/2001	2001 Geoprobe	79
AG3	7/1/2001	2001 Geoprobe	12
AK2		2001 Geoprobe	96
B1A		Round 55-63	14
B1B	1/1/1994		32.3
B2	1/1/1994		267.5
B4	11/1/2004		51
B5	1/1/1994		208
B6		Round 11	120
DM-2A	1/1/1994		1330
DM-2B	1/1/1994		ND
DM-3A	1/1/1994		119
DM-3B	1/1/1994		35.5
DM-4	1/1/1994		100
DM-5		Round 55-63	1000
DM-7	1/1/1994		79.85
DM-8		Round 55-63	10
EX-3		Round 55-63	103
G1	1/1/1994		132
G3	1/1/1994		545
H1	1/1/1994		96.1
H10	1/1/1994		25.6
H11	1/1/1994		901
H6	1/1/1994		132
H9	1/1/1994		717
MW-12	1/1/1994		93.8
MW-14		Round 15	235
MW-15	11/1/2000		283
MW-16	11/1/1999		2200
MW-17		Round 55-63	342
MW-18		Round 15	24
MW-22	11/1/1999		34
MW-23	11/1/1999		310
MW-24	11/1/1999		490
MW-25	2/1/2000		500
MW-26	11/1/1999		540
MW-27		Round 55-63	/
MW-28		Round 55-63	150
MW-29 MW-31		Round 55-63	5
10100-31	11/1/1999	NUUIIU 0	410



# **VANADIUM CONCENTRATIONS IN GROUNDWATER** 1,2

Former Rhone-Poulenc Site Tukwila, Washington

Site ID	Date	Event	Concentration
MW-34	11/1/2000	Round 10	47
MW-36	11/1/2000	Round 10	824
MW-37	5/1/2000	Round 8	26
MW-38	9/9/2013	Round 55-63	63
MW-39	9/9/2013	Round 55-63	36
MW-40	9/9/2013	Round 55-63	13
MW-41	3/19/2014	Round 55-63	348
MW-42	3/13/2012	Round 55-63	47
MW-43	3/5/2013	Round 55-63	1340
MW-44	3/5/2013	Round 55-63	373
MW-45	3/13/2012	Round 55-63	46
MW-46	3/14/2012	Round 55-63	14
RPPW-01	12/22/2011	AMEC Sediment and Shoreline Investigation	178
RPPW-02	12/23/2011	AMEC Sediment and Shoreline Investigation	10
RPPW-03	12/23/2011	AMEC Sediment and Shoreline Investigation	12
SL-07	9/2/2011	AMEC Sediment and Shoreline Investigation	173
SL-08	9/1/2011	AMEC Sediment and Shoreline Investigation	383
SL-09	9/2/2011	AMEC Sediment and Shoreline Investigation	212
SL-10	9/9/2011	AMEC Sediment and Shoreline Investigation	1540
SL-11	9/12/2011	AMEC Sediment and Shoreline Investigation	342
SL-12	9/19/2011	AMEC Sediment and Shoreline Investigation	3800
SL-13		AMEC Sediment and Shoreline Investigation	391
SL-14	9/14/2011	AMEC Sediment and Shoreline Investigation	4290
SL-15	9/21/2011	AMEC Sediment and Shoreline Investigation	1320

## <u>Notes</u>

- 1. All units in ug/L (microgram per liter).
- 2. Round 1 results from RFI do not have sampling date or reporting limits associated with the results.



## **APPENDIX B**

Data Review Memoranda



#### Memo

To: John Long Project: 087690050.00002

From: Crystal Neirby cc: Project File

Tel: (206) 342-1760 Fax: (206) 342-1761 Date: August 24, 2014

**Subject:** March and June Groundwater Sampling

Summary Data Quality Review – SDGs YD66, YD71, YP17 and YP34

This memorandum presents a summary data quality review for analyses of 11 primary groundwater samples and three trip blanks collected March 20 and June 23 and 24, 2014. The samples were submitted to Analytical Resources, Inc. (ARI), a Washington State Department of Ecology—accredited laboratory located in Tukwila, Washington. The samples were selectively analyzed for the following organic and/or inorganic analytes:

- Benzene, toluene, ethylbenzene, and xylenes (BTEX) by U.S. Environmental Protection Agency (EPA) Method 8021B Modified;
- Total metals by EPA Method 6010C;
- Total mercury by EPA Method 7470A;
- Alkalinity by Standard Method SM 2320;
- Ferrous iron by Standard Method SM3500 FeD;
- Chloride, nitrate, nitrite, and sulfate by EPA 300.0;
- Ammonia by EPA 350.1;
- Total phosphorus and orthophosphorus by EPA 365.2;
- Sulfide by EPA 376.2; and
- Total Kjeldahl Nitrogen (TKN) by EPA 351.2.

Laboratory sample delivery groups (SDGs) associated with the March and June 2014 sampling event are listed below.

Laboratory SDG	Date Collected
YD66/YD71	3/20/2014
YP17	6/23/2014
YP34	6/24/2014



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Samples were submitted to the laboratory each day upon completion of sampling. Upon receipt by ARI, the sample jar information was compared to the chain-of-custody (COC) form. The temperatures of the coolers were recorded as part of the check-in procedure and were below the maximum acceptable temperature of 6 degrees Celsius (°C).

The following observations were noted by laboratory personnel upon sample receipt.

- SDG YD66/YD71: The laboratory recorded the pH of the ammonia, metals, phosphorus, TKN, nitrate and nitrite, and sulfide samples to verify that the samples were appropriately preserved. All of the bottles submitted for the analyses requiring preservative required additional preservative in the laboratory. EPA guidelines for drinking water suggest that samples should be preserved at least 24 hours prior to analysis, and those alternate guidelines were achieved by the laboratory. The sample results are not qualified.
- <u>SDG YP17</u>: The laboratory recorded the pH of the ammonia, metals, phosphorus, TKN, nitrate and nitrite, and sulfide samples to verify that the samples were appropriately preserved. All of the bottles submitted for samples RP062314-07 required additional preservative and the dissolved metals sample bottle for sample RP062314-06 also required additional preservative. EPA guidelines for drinking water suggest that samples should be preserved at least 24 hours prior to analysis, and those alternate guidelines were achieved by the laboratory. The sample results are not qualified
- YP34: The laboratory recorded the pH of the ammonia, metals, phosphorus, TKN, and sulfide samples to verify that the samples were appropriately preserved. The bottles submitted for dissolved metals and sulfide analyses required additional preservative in the laboratory. EPA guidelines for drinking water suggest that samples should be preserved at least 24 hours prior to analysis, and those alternate guidelines were achieved by the laboratory. The sample results are not qualified

Data review is based on method performance criteria and quality control (QC) criteria documented in the site-specific Quality Assurance Project Plan (QAPP) (URS, 2002). The laboratory provided validation packages containing summarized sample results, associated quality assurance/quality control (QA/QC) data, instrument printouts, and sample preparation and injection log pages, as required by the QAPP. The data review conducted on these SDGs included a review of summarized results and QA/QC data, per the requirements set forth in Section D.1 of the QAPP (URS, 2002). The control limits provided in the QAPP are advisory limits; therefore, the most current control limits provided by the laboratory were used to evaluate the QC data. In cases where the laboratory did not track limits for an analyte, the limits in the QAPP were used. Hold times, initial and continuing calibrations, method blanks, surrogate recoveries, laboratory control samples (LCS), LCS duplicates (LCSD), matrix spike/matrix spike duplicate (MS/MSD) results, laboratory duplicate results, field duplicate results, and reporting limits were reviewed to assess compliance with applicable methods and the QAPP. If data qualification was required, data were qualified in general accordance with the definitions and use of qualifying flags outlined in EPA documents (EPA, 2008 and 2010).



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The following qualifiers may be added to the data.

- U: The analyte was analyzed for but was not detected above the reported sample quantitation limit.
- J: The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
- J+: The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample, with a possible high bias.
- UJ: The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.
- R: The sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.

#### **ORGANIC ANALYSES**

Samples were analyzed for BTEX by EPA Method 8021B, and the results were evaluated for the following QA/QC criteria:

- 1. Holding Times Acceptable
- Initial Calibrations Acceptable
   Initial calibrations were not reviewed for data packages YP17 and YP34.
- Continuing Calibrations Acceptable
   Continuing calibrations were not reviewed for data packages YP17 and YP34
- 4. Blanks Acceptable
  - o A method blank was prepared with each laboratory sample batch.
  - A trip blank was submitted for each cooler containing samples for BTEX analysis, except for the samples submitted with SDG YP34.
  - A field blank was not collected during these sample events.
- 5. Surrogates Acceptable
- 6. LCS Acceptable
- 7. MS/MSD Acceptable
- Field Duplicates Acceptable
   Field duplicates were not collected during these sample events.
- 9. Reporting Limits Acceptable



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#### **INORGANIC ANALYSES**

Samples were analyzed for conventional and metals by the methods identified in the first paragraph of this report and were evaluated for the following criteria:

- 1. Holding Times Acceptable
- Initial Calibrations Acceptable
   Initial calibrations were not reviewed for data packages YP17 and YP34.
- Continuing Calibrations Acceptable
   Continuing calibrations were not reviewed for data packages YP17 and YP34.
- 4. Blanks Acceptable

The frequency requirements for method blanks were met. Target analytes were not detected in the method blanks. Field blanks were not collected during these sample events.

- 5. LCS (or Blank Spike) Acceptable
- 6. Laboratory Duplicates Acceptable
- 7. MS Acceptable
- Field Duplicates Acceptable
   Field duplicates were not collected during these sample events.
- 9. Reporting Limits Acceptable

#### **OVERALL ASSESSMENT OF DATA**

The ARI SDGs YD66, YD71, YP17 and YP34 are 100 percent complete. Evaluation of data usability is based on EPA guidance documents (EPA, 2008 and 2010) and the QAPP (URS, 2002). Few problems were identified, and analytical performance was generally within the specified limits. The data are acceptable and meet the project's data quality objectives. The samples associated with each SDG and a summary of the data quality review are presented in Table 1.



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TABLE 1
SUMMARY OF DATA QUALITY REVIEW

Well ID	Sample	SDG	Qualified Analyte
MW-53	RP032014-53	YD66	none
MW-54	RP032014-54	YD66	none
	Trip Blank	YD66	none
MW-17	RP032014-01	YD71	none
	Trip Blank	YD71	none
MW-17	RP062314-01	YP17	none
MW-12	RP062314-02	YP17	none
H10	RP062314-03	YP17	none
MW-20	RP062314-04	YP17	none
DM7	RP062314-05	YP17	none
MW-28	RP062314-06	YP17	none
MW-27	RP062314-07	YP17	none
	Trip Blank	YP17	none
MW-29	RP062414-08	YP34	none

Abbreviations:

SDG = sample delivery group

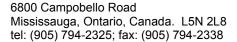
## **REFERENCES**

- U.S. Environmental Protection Agency (EPA), 2008, U.S. EPA Contract Laboratory Program National Functional Guidelines for Superfund Organic Methods Data Review: EPA 540-R-08-01, June.
- EPA, 2010, U.S. EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review: EPA 540-R-08-01, January.
- URS, 2002, Revised Hydraulic Control Interim Measure Performance Monitoring Plan Quality Assurance Project Plan: Prepared for Container Properties, L.L.C., Tukwila, Washington, September.



# APPENDIX C

EcoMetrix Report





# **MEMO**

To: David Blount, LBB LLP From: Ron Nicholson

Ref: Review of Copper Concentrations at the Date: 30 July 2010

Former R\ one-Poulenc Site in the Context of Terminating Pumping from The Isolation Cell

**DRAFT** 

The former Rhone-Poulenc site located in Tukwila, WA is under Administrative Order on Consent (No. 1091-11-20-3009(h)) where a Hydraulic Control Interim measure is in place. The site borders on the Duwamish Waterway. Historic activities associated with the production of artificial vanilla extract (vanillin) resulted in elevated concentration of toluene and copper and elevated pH in groundwater below the site. A subsurface barrier wall (the "wall") was constructed as a clay curtain encircling the property to a depth of about 70 feet bgs. The isolated subsurface zone surrounded by the barrier wall contains three extraction wells that pumped water at a combined average rate of 1.8 million gallons per year in 2009. The extracted water is routed through a treatment system before being discharged to the local sewer system.

EcoMetrix Incorporated (EcoMetrix) was retained by Landye Bennett Blumstein, LLP (LBB) to review the site conditions, hydrogeology and control measures in order to determine whether or not ongoing control measures were required for copper concentrations in the subsurface. This assignment was completed by Ronald V. Nicholson, Ph.D., a Principal and Senior Scientist with EcoMetrix. The available information for the site was reviewed and the site was inspected by Dr. Nicholson on 06 May 2010 in the company of Mr. Gary Dupuy (AMEC) and Mr. David Blount (LBB).

A review of the available information revealed key issues that are pertinent to the broad objectives of environmental protection of the Duwamish Waterway and these issues are first listed and then discussed in detail in the following text. The key issues include the following;

- the copper concentrations observed in samples from the routine monitoring wells varied from less than the quantitation limit of 2 ug/L to 156 ug/L in 2009,
- the highest copper concentrations were collected from a well outside of the isolated zone, between the wall and the shoreline of Slip 6,

- the highest concentrations of copper are associated with the highest pH values in groundwater samples,
- the barrier wall has a low permeability and is very effective at containment and is capable of maintaining a water level difference across the wall of at least one foot,
- the site is located in a regional discharge zone along the waterway with deep groundwater upwelling into the shallow aquifer across the site, outside and inside of the isolated zone.
- upward gradients prevail across most of the isolated cell as a result of pumping with the exception of the southwest corner where gradients are downward at the same time that water levels inside the cell wall remain lower than those outside the wall at that location.
- the isolated cell is completely paved over with storm sewer drainage routing,
- in the south west corner where elevated copper concentrations occur, the average copper concentrations in samples from wells inside the cell are lower than those outside the cell in the upper zone of the Shallow Aquifer, and:
- the Duwamish water levels are subject to tidal influence at the site with a mean difference of about 10 feet and a maximum difference of about 15 feet.

The property is located on the Duwamish waterway, approximately 4 miles upstream of Elliott Bay. The site was contaminated in the past as a result of industrial activities that included the use and storage of copper sulphate solutions, caustic and toluene. Elevated concentrations of toluene and dissolved copper have been measured in subsurface waters at the site and elevated pH values have been measured. An extensive monitoring well network is present at site. Remediation to date has included the installation of a clay (attapulgite) barrier wall around the site perimeter that extends to a depth of approximately 70 feet below ground surface. The wall extends into the low permeability silt layer that divides the upper "shallow" aquifer from the lower "deep" aquifer. The groundwater within the barrier wall is also pumped to maintain lower water levels inside the containment wall than outside of the cell. The site borders the Duwamish waterway on two sides and water levels are subject to typical tidal water elevation fluctuations between 10 and 15 feet.

Reference: Review of Copper Concentrations at the Former R\ one-Poulenc Site in the

**Context of Terminating Pumping from The Isolation Cell** 

**DRAFT** 

The current site use is limited to parking and storage of vehicles and the entire foot print of the area bordered by the containment wall is paved by asphalt with drainage to storm sewers.

Although elevated copper concentrations exist across the site, the most elevated values in groundwater are located at the south-west corner of the property and have been measured inside and outside of the barrier wall. The maximum copper concentration measured in monitoring wells in 2009 was 156 ug/L from well MW-44, between the wall and the shoreline on the south side of the property. If the wells in the south-west "triangle" of the site, only, are considered, the average copper concentration in well samples was 50 ug/L in 2009. The copper concentrations in the south-west triangle in 2009 are summarized in **Table 1**.

This table shows all of the wells that are sampled in the annual monitoring program. The wells in the north area of the site, including one extraction well (EX-3) are listed together and the results for those wells were not considered in the following discussion because the copper concentrations were generally lower and the wells were farther from the waterway than those in the south west area of the property. The remaining wells that are sampled were organized into groups representing wells in the upper and lower aquifers as well as those inside and those outside of the cell isolated by the wall. Of the wells sampled, it is evident that copper concentrations are, on average, higher in the upper aquifer than those in the lower aquifer, as might be expected if copper originated from releases at the surface. If only the upper aquifer is considered, it is also evident that the average concentration of copper is higher outside of the cell than inside, influenced mainly by the values at MW-44. Nonetheless, the results indicate that some elevated copper concentrations exist in groundwater outside of the isolated cell. And as demonstrated by several lines of evidence from the site data, the elevated copper outside of the wall could not have migrated through the wall from inside of the cell and had therefore predated wall construction. While the copper in groundwater outside of the cell is subject to transport with regional flow that is discharging in the vicinity of the shoreline of the Duwamish waterway and Slip 6, the copper in the cell is virtually isolated and unable to migrate to either shoreline.

Typically, the water levels within the isolated cell are maintained at lower levels than those on the outside of the wall as a result of pumping from the zone inside the wall. The pumping is intended to direct groundwater flow into the walled-off zone and to prevent release of contaminated water outward toward the waterway.

Reference: Review of Copper Concentrations at the Former R\ one-Poulenc Site in the

**Context of Terminating Pumping from The Isolation Cell** 

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It is evident that the pumping induces upward gradients in all areas except the south west corner of the isolated zone near the junction of Slip 6 and the waterway. The differences in water levels inside and outside of the isolated zone demonstrate that the clay barrier wall is very effective at restricting lateral flow through the wall. In addition, the vertical gradients demonstrate that inflow to the isolated cell is predominately upward from the lower stratum rather than laterally through the wall. The periodic downward gradients in the south east corner within the isolated zone furthermore demonstrate that groundwater within the cell is recirculating within the cell rather than moving through the barrier wall, This is concluded because the water levels within the cell remain below those immediately adjacent to, but outside of the wall and therefore, water can not flow out of the cell but is moving down in the cell and is moving laterally in the strata likely above the low permeability silt layer toward the pumping well screens. Overall, the water levels show that the barrier wall is highly impermeable and that the vast majority of water entering the cell is upward flow from the deeper stratum, induced by pumping and the lower water levels in the shallow zone of the cell. This has important implications for ongoing maintenance of the site. These observations imply that pumping is not critical for preventing lateral flow through the barrier wall. As discussed in further detail in the following text, the cell will act as a stagnant zone with no net inflows or outflows if pumping is discontinued.

The site is located within a regional discharge zone along a major water way. The upward gradients exhibited by shallow and deep wells outside of the cell confirm that flow is upward and that discharge to the water way is occurring as expected. The upward gradients are important because they show that hydraulic head values or water levels are greater at depth than near surface. The upward gradients are maintained by the higher heads at depth and lower heads, controlled by lower surface water levels in the waterway. Upward gradients are artificially induced within the cell by pumping and removal of water. Furthermore, if pumping is discontinued, there will be virtually no discharge from the cell and upward flow will no longer occur. In addition, because the cell is completely paved at surface, there is virtually no recharge downward and therefore no downward flow will occur. With no pumping, there will be no consistent or net gradients and therefore no net flow within the cell. There is no doubt that there will be periodic differences in water levels between the inside and outside of the cell as a result of tidal fluctuations. However, with no recharge to or discharge from the cell once pumping is terminated, the differences in head will not cause net flow to occur. Rather, there will be a pulsing of pressure into and out of the cell through the lower stratum as well as into and out of the cell wall with no net movement of water. The overall effect will be to induce a no-flow stagnant zone

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within the isolated cell in which transport of dissolved constituents will be controlled by diffusive processes. Once diffusion becomes dominate, it is relatively straight forward to calculate the rate of mass transport of constituents through the clay barrier wall and into the waterway sediments.

The transport of dissolved copper in the groundwater within the isolated cell will be affected by concentration gradients, the diffusion coefficient for the natural geologic materials and clay wall as well as any chemical attenuation that may occur in those media. Transport of copper out of the cell will, however, be effectively limited by migration through the clay barrier wall.

If the transport of copper through the wall becomes diffusion-limited, then the rate of copper migration or solute velocity will not only decrease to very low levels but the flux of copper through the wall will also decrease to very low values. The low flux through the wall will have the effect of controlling the copper concentrations to low levels in groundwater flowing upward on the outside of the wall. The calculation in Attachment 1 illustrates the potential decrease in copper concentration from the inside to the outside of the wall. Starting with a copper concentration of 150 ug/L inside the wall that is approximately equal to the maximum observed value in 2009 at MW-27 of 138 ug/L, the calculated concentration outside of the wall would be less than 0.01 ug/L as a result of the low flux of copper through the wall. These calculations show that concentrations outside of the cell would be well below the NRWQC value of 12.33 ug/L if pumping of the cell was discontinued and the water levels inside and outside of the cell were similar.

This analysis ignored chemical controls and attenuation of copper in order to provide a conservative evaluation of the flux through the wall. Reversible attenuation will affect the time required for transport of copper through the wall with longer times required for greater attenuation. Attenuation can also affect the flux when diffusion is the dominant transport mechanism. Attenuation is commonly modelled in terms of a water to solid partitioning coefficient or  $K_d$  that is used to calculate a retardation coefficient (R) that is defined as

$$R = 1 + K_d * \rho_b / n$$

in which  $\rho_b$  is the dry bulk density (kg/m³) and n is the porosity (m³/m³). The ratio of  $\rho_b/n$  is typically close to a value of 4 for porous media. The  $K_d$  model assumes reversible distribution in which the ratio of the concentration in the solid (C<sub>s</sub>) to that in the water (C<sub>w</sub>) is a constant or;

$$K_d = C_s / C_w$$

Values have been measured for  $K_d$  related to copper sorption in a variety of media. Values range from highs near 1 x 10 $^8$  L/kg in purified peat humic acid (Kinniburgh et al, 1998) to values as low as 3950 kg/L in Malaysian soils (Yaacob et al, 2008). The attapulgite clay in the barrier wall likely represents a material with a high adsorption capacity for copper with a correspondingly high  $K_d$  value. If we assume the lowest value measured in the Yaacob et al study of about 4000 L/kg, the resulting retardation coefficient (R) is estimated to be about 16,000. When retardation is considered in diffusive transport, the diffusion equation is modified to include R and the equation becomes;

$$F_{diff} = \frac{dc}{dx} \frac{D}{R}$$

This shows that the flux of a retarded substance will have a flux that is R times lower than that of a non-retarded substance. Therefore, the copper flux and the resulting concentrations in groundwater will be lower than those values discussed above by a factor of R or for the low  $K_d$  value, by a factor of 10,000 times. The maximum concentration of copper in groundwater outside of the barrier wall was shown in Attachment 1 to be much less than the NRWQC value of 12.33 ug/L with no retardation considered. If retardation docs occur as expected in the clay comprising the wall, then the flux and resulting maximum groundwater concentration outside the wall will be lower than those estimated when retardation was not factored into the calculations.

The distribution coefficient of  $K_d$  model provides a basis for calculating transport rates and fluxes in groundwater systems but is not intended to represent the mechanistic chemical interactions that can occur for metals and other solutes such as copper. The following discussion provides a background for understanding potential chemical interactions of copper in groundwater at the site.

The average copper concentrations from the 2009 annual monitoring report were plotted against the average pH values as shown in **Figure 1**. It is evident that copper concentrations are lower with lower pH values. The high pH values are considered to associated with caustic (NaOH) that was also used in the vanillin production process and was likely released with the copper, is the cause of the pH values between 10 and 11. Copper chemistry and mineralogy is relatively well understood in relation to solids that may potentially control the

concentrations of copper in geologic media. Some candidates for solid controls, that are also linked to pH include the following that are known to exist in nature or form in pH-controlled solutions with copper present;

- Malachite Cu<sub>2</sub> (CO<sub>3</sub>(OH)<sub>2</sub>
- Copper hydroxide Cu<sub>2</sub>(OH)<sub>2</sub>
- Cuprite Cu<sub>2</sub>O
- Copper Metal Cu

Although there are many other copper compounds and minerals that may possibly form under specific chemical conditions, those listed above are considered to be the most likely candidates for controlling copper concentrations in groundwater systems. While malachite and copper hydroxide contain the expected oxidized form of copper as Cu +II, cuprite contains a more reduced form of copper as Cu +I and copper metal contains the most reduced form as Cu 0. Copper hydroxide is known to form in treatment systems when the pH is raised to 6 or higher. Malachite is known to form when dissolved Cu<sup>2+</sup> comes in contact with calcite (CaCO<sub>3</sub>) in geologic materials. Cuprite and copper metal can only form in reducing conditions, driven by the presence of organic matter after Cu +II can be converted to Cu +I or Cu 0.

The theoretical concentrations of dissolved copper resulting from equilibrium controls by the four solids are shown as a function of pH as curves in **Figure 2**. The copper concentrations were calculated by PHREEQC (Parkhurst and Appelo, 1999). The data points represent the average values for copper and pH from the 2009 monitoring program. Copper concentrations are shown on a log scale in order to allow presentation over a large range of values. It is evident that no one solid appears to control copper concentrations over the entire range of pH values. While it appears that copper hydroxide may play a role at high pH, cuprite controlled concentrations are more similar to the observed concentrations at lower pH values. It is also evident that none of the solids considered show a pH-concentration trend or slope similar to that exhibited by the data. Overall, this comparison suggests that the control on copper concentrations in groundwater at the site is likely the result of sorption that is pH dependent rather than being related to a specific solid phase control. Nonetheless, the pH control on sorption appears to be quite important.

The overall trend shows that copper concentrations are lower at lower pH values with some exceptions. Although this correlation as shown in **Figure 1** may have resulted from co-release of copper and caustic, it is also clear that not all

elevated copper concentrations are associated with high pH in groundwater. This strongly suggests that there is a cause and effect relationship to the correlation between copper and pH. This is important for the overall control of copper concentrations during transport in the groundwater at the site.

While transport of elevated copper concentrations and high pH water will and is occurring outside of the isolation cell as a result of natural groundwater flow conditions that result in regional discharge near the Duwamish waterway. The high pH water, caused by release of caustic, will react with solids and during mixing with ambient groundwater to neutralize the pH. Neutralization will occur as a result of reactions such as ionic exchange with surfaces of geologic materials in reactions such as follows;

$$S-OH+OH^- \rightarrow S-O^- + H_2O$$

In this case, S represents the surface charge layer on the solids. Common solids that have surface charge layer and can react like this include clay minerals, iron and aluminum hydroxides and calcite as shown by Stumm and Morgan (1996). Another common reaction that will neutralize high pH water is the precipitation of calcite. If the ambient groundwater is near equilibrium with respect to calcite, mixing with high pH water will cause the water to become supersaturated with calcite and precipitation will occur and H<sup>+</sup> will be releases as follows;

$$Ca^{2+} + HCO_3^- \rightarrow CaCO_{3(s)} + H^+$$

The released acid will consume the excess OH<sup>-</sup> that is the cause of the high pH.

As the high pH water is neutralized and the pH of the groundwater containing elevated copper continues to be transported through the geologic materials, the copper will likely be sorbed to the solids to be consistent with the relationship between copper concentrations and pH shown in **Figure 1**. This expected neutralization combined with additional sorption of copper provides natural attenuation that is protective of the receiving environment when copper transport occurs. Additionally, it is well known that copper adsorption onto organic material such as peat or sediments with organic carbon is much greater than that in inorganic geologic materials. The shallow sediments of the Duwamish waterway likely have higher organic carbon contents than the underlying geologic materials and will therefore have a greater sorption capacity for copper with higher  $K_d$  values. Greater sorption in the sediments of the waterway results in lower concentration in groundwater that seeps into the waterway.

Therefore, although the concentrations of copper in groundwater that result from copper migration through the barrier wall will be very low in the absence of pumping, other natural attenuation mechanisms, discussed above, will act to further reduce copper concentrations in groundwater.

In conclusion, the following points support a decision to cease pumping of the isolation cell:

- the barrier wall that comprises the isolated cell has a low permeability and represents a very effective hydraulic barrier to prevent significant flow out of the cell,
- there are no hydraulic inputs to the cell because it is currently paved over and all precipitation is routed as runoff to a storm sewer system,
- the absence of net hydraulic gradients across the wall after pumping ceases will result in diffusion as the primary transport mechanism for copper from the inside to the outside of the wall,
- conservative diffusion calculations show that the resulting copper concentrations in groundwater outside of the cell will be less than 1 ug/L and much less than the NRWQC value of 12.33 ug/L,
- there are currently elevated concentrations of copper in groundwater outside of the isolation cell that pre-date the barrier construction and no adverse effects have been noted as a result of those copper concentrations,
- it is evident that pH influences copper concentrations and that the lower pH values that are representative of ambient groundwater conditions will provide greater natural attenuation of copper during groundwater transport,
- natural attenuation of copper will be greater in organic rich sediments of the Duwamish waterway and copper concentrations that enter the waterway in groundwater seepage are expected to be very low, regardless of whether the copper originated inside or outside of the isolated cell,
- ongoing monitoring at the site can continue after pumping ceases and because of the absence of input flows to the isolated cell as well as the

30 July 2010 David Blount Page 10 of 15

Reference: Review of Copper Concentrations at the Former R\ one-Poulenc Site in the

**Context of Terminating Pumping from The Isolation Cell** 

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nature of natural groundwater flow, the risks of uncontrolled migration of copper from the cell will be non-existent.

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## Attachment 1

The following calculation illustrates the effect on copper concentrations outside of the barrier wall if diffusion dominates solute transport through the wall.

The governing equation for diffusive transport across the wall is;

$$F_{diff} = \frac{dc}{dx} D$$
 (equation 1)

in which  $F_{\rm diff}$  is the copper flux (ug/m²/s), c is the copper concentration in groundwater (ug/L), x is the thickness of the wall (m) and D is the effective diffusion coefficient for copper in the wall (m²/s). The copper concentration inside the wall can be represented by a value of 150 ug/L that is near the maximum value shown in **Table 1** of 138 ug/L in the upper aquifer within the cell. The thickness of the wall is 6" (or 0.15m). A value for the effective diffusion coefficient of 6 x  $10^{-10}$  m²/s, representing glaciolacustrine clay (Spitz and Moreno, 1996, Table D1) can be used for illustrative purposes. Even though diffusion through the wall will require a long time to occur, the maximum flux can be calculated at steady-state when the outside concentration remains near a value of zero (see **Figure A1**). Therefore, equation 1 provides an estimate of the maximum flux through the wall for the condition for which C outside equals 0 ug/L.

The flux of copper that exists the outside surface of the wall will enter the groundwater that is flowing vertically upward along the outside of the wall and will mix with this groundwater.

Two additional assumptions are required to calculate the final concentration of copper in groundwater outside the wall that originated from the copper inside the wall. First, the depth zone over which the flux of copper is expected to occur must be selected. This depth can be assumed to be 40 or two-thirds of the wall depth in order to provide a very conservative zone of elevated copper inside the wall. Second, the horizontal zone of mixing in groundwater along the outside of the wall must be assumed. This thickness along the outer zone of the wall can be conservatively assumed to be 6 inches (0.15m) wide similar to the width of the barrier wall.

The upward flow rate through that zone is then calculated from Darcy's equation;

$$V_{up} = Ki$$
 (equation 2)

in which  $V_{\rm up}$  is the volumetric flux (m³/m²/s), K is the hydraulic conductivity of the upper aquifer (1x10<sup>-4</sup> m/s) and i is the upward vertical gradient (m/m). At wells MW-43L and MW-44U, the differences in water elevations in 2009 varied between -2.5 to +3.5 feet. Over the 20 vertically between well screens, these evaluation differences equate to a downward gradient of -0.125 to an upward gradient of +0.175. Downward gradients occur occasionally as a result of tidal fluctuations. However, the dominant direction of flow is upward near the shoreline outside the wall. As a conservative estimate of gradient, an elevation difference of +1 foot was assumed, resulting in a vertical upward gradient of +0.05. Therefore the volumetric flux upward, adjacent to the wall would be;

$$V_{up} = 1x10^{-4} \, \text{m/s} * 0.05 = 5x10^{-6} \, \text{m}^3 \, / \, \text{m}^2 \, / \, \text{s}$$

and the total upward flow (per metre width of wall) will be;

$$Q_{up} = 5x10^{-6} \text{m}^3 / \text{m}^2 / \text{s} * 0.15 \text{m} = 7.5x10^{-7} \text{m}^3 / \text{m} / \text{s}$$
$$= 7.5x10^{-4} \text{L} / \text{m} / \text{s}$$

With a copper flux of,

$$F_{\text{(diff )}} = 6x10^{-10} \frac{\text{m}}{\text{s}}^2 x(150 - 0) \text{ug} / \text{L} / 0.15 \text{ m} * 1000 \text{ L} / \text{m}^3$$
$$= 6x10^{-7} \text{ug} / \text{m}^2 / \text{s}$$

The resulting concentration in the upward flowing groundwater outside of the wall is,

$$C_{out} = 6x10^{-7} ug/m^2/s*12.2m/7.5x10^{-4} L/m/s$$
  
= 0.01ug/L

Reference: Review of Copper Concentrations at the Former Rhone-Poulenc Site in the

**Context of Terminating Pumping from The Isolation Cell** 

**DRAFT** 

Table 1: Summary of 2009 Copper concentrations in southwest area of site arranged by zones

Well	Location	Aquifer	Copper Concentration (ug/L)				
			Mar- 09	Jun- 09	Sep- 09	Average -2009	Zone Average
MW-17	Inside	Upper	26	NS	13	20	
MW-27	Inside	Upper	34	NS	138	86	
MW-28	Inside	Upper	54	NS	83	69	
MW-28 dup	Inside	Upper	73	NS	97	85	
MW-29	Inside	Upper	9	NS	39	24	57
MW-40	Outside	Lower	5	8	10	8	
MW-42	Outside	Lower	10	NS	12	11	
MW-43	Outside	Lower	38	60	60	53	
MW-45	Outside	Lower	12	NS	12	12	
MW-45 dup	Outside	Lower	11	NS		11	19
DM-8	Outside	Upper	4	NS	2	3	
MW-41	Outside	Upper	65	29	80	58	
MW-44	Outside	Upper	102	150	149	134	
MW-44 dup	Outside	Upper	NS	150	156	153	
MW-46	Outside	Upper	2	NS	2	2	70

NS - not sampled

Figure 1: Average 2009 copper concentrations plotted against average pH values.

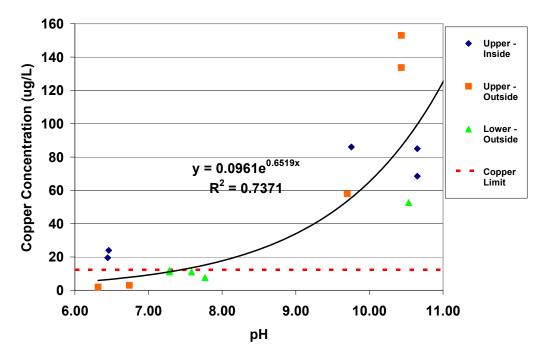
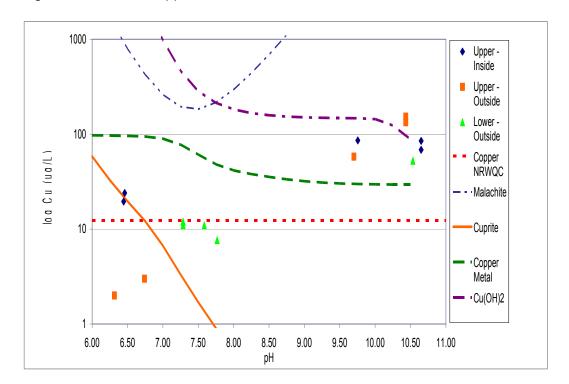
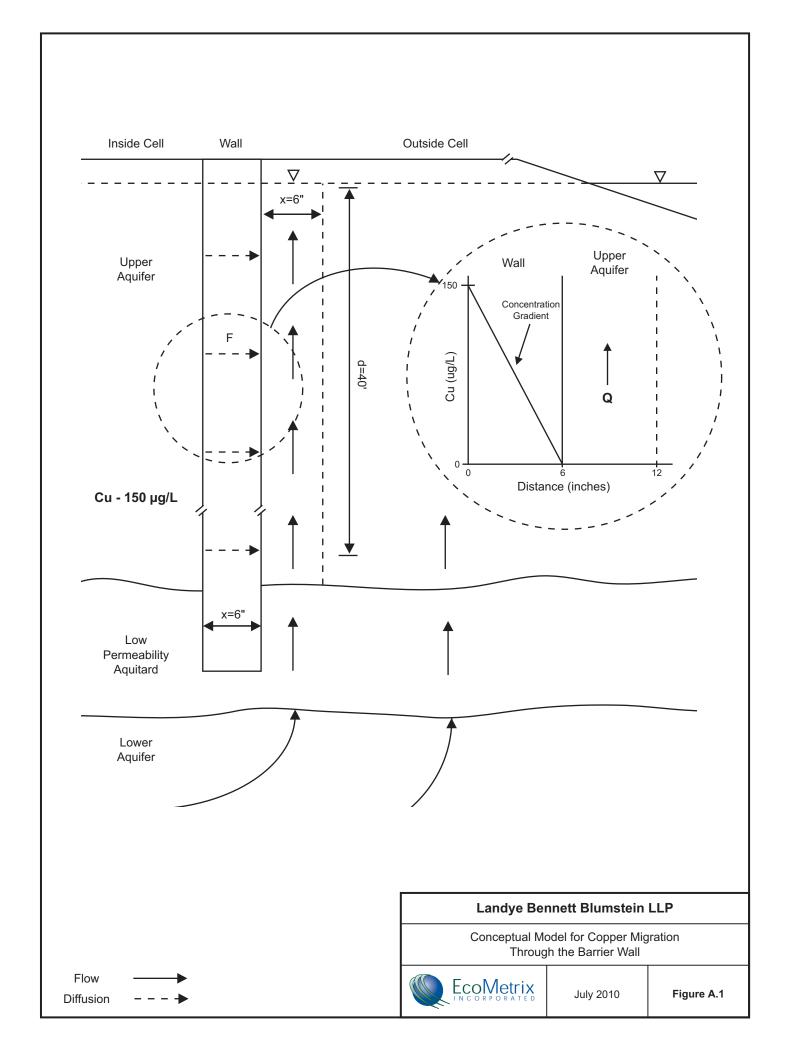


Figure 2: Predicted copper concentrations for selected solids.







# APPENDIX D

CO<sub>2</sub> Injection Pilot Study Work Plan



# CO<sub>2</sub> INJECTION PILOT STUDY WORK PLAN

Former Rhone-Poulenc Site Tukwila, Washington

Prepared for:

# **Container Properties**

Tukwila, WA

Prepared by:

# **AMEC Environment & Infrastructure, Inc.**

600 University Street, Suite 600 Seattle, Washington 98101 (206) 342-1760

August 2014

Project No. 0087690050.00010.\*\*\*\*



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# **Drawings**

Drawing P&ID-01 CO<sub>2</sub> Injection System Process and Instrumentation Diagram

#### **Attachments**

Attachment 1 Calculations for CO<sub>2</sub> Injection Pressures



# CO<sub>2</sub> INJECTION PILOT STUDY WORK PLAN

Former Rhone-Poulenc Site Tukwila, Washington

#### 1.0 INTRODUCTION

The former Rhone-Poulenc facility (site) is located adjacent to the Duwamish Waterway in Tukwila, Washington. This CO<sub>2</sub> Injection Pilot Study Work Plan (work plan) was prepared to document plans for performing a pilot study to assess the use of CO<sub>2</sub> injection to neutralize portions of the site affected by high pH. Results from the pilot study will be used to complete the Corrective Measures Study (CMS) that is being performed to address the requirements of the Resource Conservation and Recovery Act (RCRA) Administrative Order on Consent (Order) No. 1091-11-20-3008(h). The CMS Work Plan includes a screening of remedial technologies in the CMS for the site. The technology screening identified CO<sub>2</sub> injection as the preferred technology for neutralizing groundwater affected by high pH in the Shoreline Area. This technology has had a limited history of use; site-specific testing is needed to fully assess its applicability and to collect the detailed information needed to evaluate CO<sub>2</sub> injection as a component of the corrective measures alternatives.

This work plan documents the objectives, testing plan, and monitoring plan for performing a pilot study that will assist in the technical and cost evaluation of using CO<sub>2</sub> to neutralize high pH soil and groundwater. The high pH target area lies in the Shoreline Area, which is located between the hydraulic control interim measure (HCIM) Area barrier wall and the Duwamish Waterway and Slip 6. The affected area was affected by historical releases of sodium hydroxide from a storage tank that was located near the southwest corner of the site. Due to potential adverse effects to the adjacent surface water and site workers that could be caused by injection of acid, CO<sub>2</sub> was selected as the preferred acid as the acid gas would have limited effect on surface water and site workers if releases occurred during injection. In addition, the pilot study will be performed inside the barrier wall to limit potential adverse effects while performing the study. The pilot study area is shown on Figure 1

#### 1.2 STATEMENT OF THE PROBLEM

As discussed in Section 3 of the CMS Work Plan, elevated pH levels have been observed in groundwater in the southwest portion of the site, both inside and outside the barrier wall. The high pH area is delineated on Figure 1, based on the maximum pH values observed in site groundwater monitoring from March 2008 to present, and data from the 2011 shoreline investigation. The maximum pH measurement shown on Figure 1 is 11.3, measured in push probe SL-12, in the Shoreline Area along Slip 6 west of the MW-43/44 well cluster. Historical sample locations and data collected prior to 2008 are also shown on Figure 1. The contoured data on Figure 1 show that the



area of elevated groundwater pH values is limited to the southwest corner of the site and includes a portion of both the HCIM and Shoreline Areas. This figure also shows that pH levels elsewhere on the site are near neutral and slightly acidic, as normally observed for groundwater in this area. As discussed in the CMS Work Plan, the pH levels tend to be highest at depths ranging from approximately 35 to 50 feet below ground surface (bgs).

High pH groundwater and soil located inside the HCIM Area wall have been effectively isolated from the environment and have limited potential to cause adverse impacts on human health and the environment. The area of elevated pH located in the Shoreline Area along Slip 6 and the Duwamish Waterway is not contained, and high pH groundwater may be released to the nearby surface water. The high pH area to be addressed in the CMS lies within the pH 8.5 contour within the Shoreline Area (Figure 1); this area is defined as the high pH target area. Other contaminants are present in the high pH target area at concentrations exceeding their preliminary remediation goals; neutralization of the high pH may be necessary to successfully remediate the other constituents of concern in this area.

### 1.3 HIGH PH TARGET AREA CONDITIONS

The site has been characterized from historical investigations discussed in Sections 2 and 3 of the CMS Work Plan. The hydrologic conditions that affect the high pH target area are briefly described below, along with a summary of groundwater results for pH and other important groundwater constituents that may affect neutralization of high pH soil and groundwater.

## 1.3.1 Hydrogeologic Conditions

#### 1.3.1.1 HCIM Area

The barrier wall was installed in 2003 and is used to contain contaminated soil and groundwater within the HCIM Area, where most of the site manufacturing and production occurred. The HCIM barrier wall is keyed into the Upper Aquitard, as discussed in Section 2 of the CMS Work Plan. The HCIM Area is shown on Figure 1. Since late February 2004, the mean groundwater level inside the barrier wall, as measured in MW-49, has been more than 1 foot below the mean groundwater level measured in the downgradient control well outside of the barrier wall, DM-8, located in the Shoreline Area. These measurements indicate that a constant, inward mean hydraulic gradient has been achieved and maintained for the HCIM Area. Groundwater is pumped from the HCIM Area at a rate of about 4 gallons per minute. The barrier wall and groundwater recovery system have effectively isolated groundwater within the HCIM Area from groundwater outside the barrier wall and beneath the aquitard underlying the HCIM Area. The surface cover for the HCIM Area limits infiltration of surface water. Most of the groundwater recovered from the HCIM Area is expected to flow upward, through the aquitard. For more discussion on the hydrogeologic conditions of the HCIM Area, see Section 2 of the CMS Work Plan.



#### 1.3.1.2 Shoreline Area

The Shoreline Area consists of the strip of land west of the HCIM Area along the Duwamish Waterway and south of the HCIM Area along Slip 6. The Slip 6 portion of the Shoreline Area extends to the Boeing property line along the north side of Slip 6. Groundwater flow in the Shoreline Area is essentially stagnant. The presence of the barrier wall along nearly the entire Shoreline Area means that groundwater cannot flow freely from the HCIM Area toward the adjacent surface water, as occurred prior to construction of the barrier wall. Therefore, tidal changes from the Duwamish Waterway and Slip 6 move the nearly stagnant water within the Shoreline Area up and down along this strip of land, and surface infiltration from unpaved portions of the Shoreline Area infiltrate and drain to surface water within shallow Shoreline Area soils. The presence of the barrier wall near the eastern end of the Slip 6 Shoreline Area results in groundwater entering Slip 6 near the southeast corner of the barrier wall. Additional discussion of groundwater conditions in the Shoreline Area is presented in Section 2 of the CMS Work Plan.

## 1.3.2 Groundwater Chemistry Data

Groundwater data have been collected at the site as part of several investigations and monitoring events since the mid-1990s. As noted above, pH data for groundwater collected since 2008 were used to delineate the high pH area (Figure 1 and Table 1); the more recent pH data were used to reflect current groundwater conditions. These data were taken from quarterly monitoring reports and routine monitoring since January 2008, the Shoreline Soil and Groundwater Characterization Data Report (AMEC, 2012), and non-routine sampling conducted in 2014, as indicated on Table 1.

Table 2 summarizes the pH data, total alkalinity and total silicon for existing wells located within the pilot study area. The pH data in Table 2 were collected from 2008 to present. The total alkalinity and silicon data for MW-29, MW-53, and MW-54 were collected in 2014. For the wells outside the barrier wall (MW-43 and MW-44), the total alkalinity and total silicon data in Table 2 are from the 2005 quarterly monitoring data. MW-29 data in Table 2 also includes silicon and alkalinity data from the 2005 quarterly monitoring data. The Table 2 data reflect the range expected for these key chemistry variables for groundwater within the high pH target area. Table 3 summarizes overall water chemistry data for site groundwater. The Table 3 data were taken from Round 28 monitoring data in June 2005; this monitoring event occurred after Shoreline Area groundwater had adapted to conditions after barrier wall construction and during the period of detailed groundwater chemistry monitoring.



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#### 2.0 CHEMICAL EQUILIBRIUM MODELING

To support conceptual design of the neutralization system for the pilot study area, chemical equilibrium modeling was used to analyze groundwater chemistry in high pH areas and model results were compared to data collected within the high pH target area wells. The chemical model using Visual MINTEQ was developed by using detailed water chemistry results for MW-44, one of the wells in the target area with the highest detected pH readings outside the HCIM area. The water chemistry data was used to assess groundwater chemistry throughout the target area and to run simulations for water chemistry changes caused by CO<sub>2</sub> injection. The purpose of the modeling was to estimate how much carbonic acid would be required to neutralize groundwater within the high pH target area, the resulting changes in chemical equilibria caused by adding an acid into site groundwater, and the magnitude of solids precipitation caused by acid addition. These factors were used to support the design of the pilot study inside the barrier wall. The high silicon concentrations in high pH groundwater are expected to cause significant precipitation of silica as the pH is reduced. The precipitated solids could affect aquifer characteristics and cause fouling, which may affect follow up injections in a fixed injection well.

### 2.1 METHODS

Detailed groundwater chemistry was monitored in the Shoreline Area after barrier wall completion to determine the effect of the barrier wall on the groundwater chemistry; the detailed groundwater chemistry data were collected from the third quarter of 2003 to the fourth quarter of 2005. Figure 2 shows the trends for pH and total dissolved silicon in MW-44 over this monitoring period. As shown on Figure 2, the pH and silicon trends appear to be leveling out and approaching a new state of equilibrium between the soil and stagnant groundwater after barrier wall construction in 2003. Chemical equilibrium modeling was performed using the groundwater composition for the second quarter of 2005 in well MW-44, as it has historically been one of the highest pH wells. Data from the second quarter of 2005 was used as the pH appeared to be leveling out at this point and the dissolved silicon concentration was slightly higher than the average observed in this well in 2005. The water chemistry data for MW-44 that was used for modeling is summarized in Table 3. Table 3 also shows groundwater data for the other wells sampled for the Round 28 monitoring report.

Visual MINTEQ was used to model the aqueous equilibria for neutralizing groundwater based on the MW-44 composition from 2005. The initial constituent concentrations from the laboratory analyses were input into the model to establish the initial equilibrium speciation. In order to model alterations to the water chemistry due to injection of CO<sub>2</sub>, the modeled system was assumed to be in equilibrium with ferrous hydroxide, amorphous silica, and gaseous CO<sub>2</sub>. For initial conditions, the gaseous CO<sub>2</sub> partial pressure was established for equilibrium with the measured alkalinity. Injection of CO<sub>2</sub> was simulated by increasing the partial pressure of CO<sub>2</sub> in a series of steps and recalculating aqueous



equilibria. The increased CO<sub>2</sub> partial pressure increased the amount of carbonic acid that dissolved into the system, simulating what would happen if CO<sub>2</sub> was injected to the subsurface, creating increasing partial pressures. For each incremental increase in CO<sub>2</sub> partial pressure, the aqueous chemical system was speciated using Visual MINTEQ to predict the resulting pH, dissolved silica, and total dissolved iron. Precipitation was determined by the change in total species concentration of silicon and iron for each CO<sub>2</sub> partial pressure increment. Precipitated solids were assumed to be amorphous silica (SiO<sub>2</sub>) and ferrous hydroxide. Precipitation of other constituents was considered to be insignificant due to low initial concentrations, and was not accounted for in the modeling.

#### 2.2 GROUNDWATER MODELING RESULTS

The results of the equilibrium modeling are shown on Figure 3 as a dashed red line. Figure 3 also shows pH versus SiO<sub>2</sub> for wells MW-41, MW-43, and MW-44 from the third quarter of 2003 to the fourth quarter of 2005, with pH ranging from 9.3 to just over 11. As shown, the model predictions for the equilibrium dissolved silica concentration compare well with the sample analyses for these wells up to a pH of about 10.8. New data collected in 2014 for MW-53 is shown on Figure 3 and indicates agreement between the model predictions and the analysis results. This agreement indicates that the assumptions used to develop the chemical equilibrium model, including using the water composition data for MW-44, are applicable to actual Shoreline Area groundwater conditions at the site. The model output, using water composition data from one data set for MW-44, reproduced with reasonable accuracy the measured concentrations of silica in wells MW-41, MW-43, MW-44, and MW-53, indicating that high pH groundwater at the site is saturated with amorphous silica. The model results indicate that approximately 1,300 milligrams per liter (mg/L) of solids, primarily consisting of amorphous silica, will precipitate from the addition of CO<sub>2</sub> to bring the pH down to 8.5 standard units (SU). The model also predicts that a total of 1,780 mg/L of CO<sub>2</sub> must be added to the groundwater to reduce the pH of the water from 10.8 to 8.5 SU. Figure 4 shows the total amount of CO<sub>2</sub> needed to lower the pH for MW-44 from an initial pH of 10.8 to 8. The CO<sub>2</sub> dose to neutralize groundwater with lower initial pH values can be estimated from the difference between starting and ending pH values.

While the model may be used to gain an understanding of how groundwater will behave during neutralization; several limitations should be noted. First and foremost, the model does not address the soil buffering capacity for the soils assumed to be in equilibrium with the groundwater at the present time. Aqueous equilibria and precipitation reactions will proceed relatively rapidly, but reactions with the soil will proceed more slowly due to surface and pore diffusion and dissolution. It is expected that the soil buffering capacity will slowly cause the groundwater pH to increase after rapid neutralization of the groundwater. It is expected that amorphous silica will precipitate onto soil particles as a result of groundwater neutralization. The increase in pH from soil reactions is expected to cause partial dissolution of amorphous silica back into the water column as the pH rebounds.



#### 3.0 PILOT STUDY OBJECTIVES

The CO<sub>2</sub> injection pilot study will be performed to evaluate the feasibility of CO<sub>2</sub> injection to neutralize the high pH in the target area, assess injection costs, and evaluate factors affecting remedy design. The pilot study objectives are described in the individual subsections below. These objectives support evaluation of the effectiveness of CO<sub>2</sub> injection in achieving neutralization objectives and provide information needed for the conceptual designs and cost estimates needed to complete the CMS. The pilot study also may provide information that could be used in full-scale design if the technology is determined to be feasible.

### 3.1 CO<sub>2</sub> Consumption Assessment

The pilot study will determine the  $CO_2$  demand to neutralize a unit volume of both soil and water in the target area. Prior to  $CO_2$  injection, the high pH groundwater will be in equilibrium with the soil matrix. The chemistry of the soil surfaces, including internal pore surfaces, will be affected by the high pH groundwater which has been in contact with these soils for decades. It is anticipated that as  $CO_2$  is injected and dissolves into the groundwater as carbonic acid, the carbonic acid will neutralize groundwater alkalinity, decreasing the groundwater pH and forming solid amorphous silica that will precipitate onto subsurface soils. As the pH in the groundwater declines, a concentration gradient will form between the soil surfaces and the water, resulting in a two-way diffusion of acid compounds from the water to the soil surface and high pH compounds back into the water column. This diffusion process is expected to cause a rebound in the groundwater pH. The pH rebound will be slower than aqueous equilibria and precipitation reactions due to the kinetics of the diffusion and dissolution processes.

The total dose of CO<sub>2</sub> needed to achieve full neutralization will depend on the groundwater alkalinity and the soil buffering capacity. To achieve neutralization, both soil and groundwater will need to be neutralized. The groundwater carbonic acid demand may be determined from the measured groundwater alkalinity and concentrations of other constituents determined from sample analyses and using a model such as Visual MINTEQ, as described above. The soil buffering capacity is more complex and must be empirically evaluated to determine the total acid dose to fully neutralize the subsurface to a defined pH. Methods to evaluate the soil buffering capacity are outlined in Section 4.2 of this work plan.

## 3.2 CO<sub>2</sub> UTILIZATION EFFICIENCY

The utilization efficiency for CO<sub>2</sub> is the percentage of injected CO<sub>2</sub> that dissolves into groundwater and is available for neutralizing groundwater. It is expected that only a portion of injected CO<sub>2</sub> will dissolve into the groundwater; undissolved CO<sub>2</sub> will migrate to the surface and be released to the atmosphere. CO<sub>2</sub> utilization efficiency is important in developing a site-wide design and determining the cost-



effectiveness of injecting gaseous  $CO_2$  into the subsurface for neutralization. It is expected that the utilization efficiency will be affected by the injection rate. As the  $CO_2$  is injected, the gas will follow preferential flow paths such as high permeability soils, natural or constructed surface vents, or debris in the ground that may provide a conduit for the gas. High injection rates would likely cause channels of gas to form from the injection point to the vadose zone. In order to assess the efficiency of utilization for  $CO_2$ , changes in groundwater total carbonate must be monitored before and after injections to estimate dissolution of  $CO_2$  and a means to measure vented  $CO_2$  is needed to assess gas loss to the atmosphere. It is expected that the utilization efficiency can only be approximated, as migration pathways for injected  $CO_2$  will be difficult to determine.

### 3.3 CO<sub>2</sub> Injection Rates and Injection Pressures

In conjunction with measuring the CO<sub>2</sub> utilization efficiency, the relationship between injection pressure and injection rate needs to be evaluated in the field. Injection pressures will depend on aquifer and well characteristics, requiring site-specific measurements. As silica precipitates during neutralization, the injection pressures required to maintain a given injection rate may increase and the pilot study should assess the potential for these changes.

#### 3.4 RADIUS OF INFLUENCE

The radius of influence (ROI) for CO<sub>2</sub> injection wells must be evaluated to determine the number of wells needed to effectively remediate the target area without affecting areas with acceptable pH levels and to avoid loss of CO<sub>2</sub> to adjacent surface water bodies. The ROI should be measured for different gas injection flow. As the CO<sub>2</sub> injection flow rate is increased, within limits, the ROI is expected to increase. However, excessively high injection rates may create gas channels that would decrease the ROI.

#### 3.5 GROUNDWATER AND SOIL CHEMISTRY

Characterization of the soil and groundwater chemistry due to injection of CO<sub>2</sub> will provide insight into the groundwater/soil systems' response to changes in pH that may affect ongoing injection operations and attainment of neutralization objectives. The pilot study will include groundwater sampling and analysis to assess water chemistry changes caused by CO<sub>2</sub> injection. The groundwater analyses will be used to support and assess equilibrium modeling for system analysis.

#### 3.6 ASSESSMENT OF PH REBOUND

As discussed in Section 3.1, pH rebound will likely occur after the pH of the groundwater is reduced and as the soil buffering capacity reacts slowly. The time scale for pH rebound must be assessed in the pilot study—the rate of rebound will likely change after multiple injections and is likely dependent on several factors, such as natural variation in soil type, precipitation of amorphous silica, and



groundwater pH. To gain a better understanding of pH rebound, groundwater pH will be monitored within the neutralized area during the pilot study.



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#### 4.0 PILOT STUDY METHODS

Pilot testing will be conducted to assess injection of gaseous CO<sub>2</sub> into areas impacted by high pH to reduce the pH to below 8.5 SU and to achieve the objectives described in Section 3 of this work plan. The pilot testing will be conducted inside the barrier wall to reduce the potential for adverse impacts to adjacent surface water that could occur during injections in the Shoreline Area. This location will support evaluation of a wider range of conditions than could be safely evaluated in the Shoreline Area. Groundwater chemistry and soil composition within the high pH areas inside the barrier wall appear to be similar to conditions within the Shoreline Area; outside the barrier wall, as can be seen by comparing the data point for MW-53 (inside the barrier wall) to the pH results for MW-41, MW-43, and MW-44 (outside the barrier wall) (Figure 3).

The area near well cluster MW-43/MW-44 in the Shoreline Area has one of the highest pH levels observed at the site (Figure 1). Pilot testing will be conducted using MW-54 as the injection well; this well is located directly across the barrier wall from wells MW-43/MW-44 and the high pH target area (Figure 5. MW-54 is also located near the barrier wall, which will allow effects of the barrier wall on CO<sub>2</sub> injection to be evaluated. Table 2 shows pH, total alkalinity, and total silicon data for wells MW-43/MW-44, wells MW-53/MW-54, and MW-29, which will be a monitoring well. These are some of the key water chemistry parameters affecting neutralization. Well MW-53, which is about 8 feet away from MW-54, is completed in the shallow portion of the Upper Aquifer, and had a pH of 10.79, as measured in the laboratory during alkalinity testing of a sample collected in the first quarter of 2014. This pH is slightly lower than the pH observed in wells MW-43/MW-44 in the first guarter of 2014. The pH in MW-54, completed in the deep portion of the Upper Aguifer, had a pH of 10.52 taken during field measurements in June 2014. The total alkalinity in wells MW-53/MW-54 is lower than observed in wells MW-43/MW-44. Results for total silicon in wells MW-53/MW-54 are generally consistent with results for wells MW-43/MW-44, although the single silicon measurement for MW-54 was significantly higher than for wells MW-43/MW-44 and the alkalinity was lower in MW-53/MW-54. Sampling for water chemistry in MW-53/MW-54 has been limited, but wells MW-43/MW-44 were regularly sampled for water chemistry during 2004–2005. MW-54 is located about 37 feet from the wells MW-43/MW-44 and is located near the edge of the high pH target area, which will support evaluating effects of injection on areas with lower pH levels, as will be encountered when approaching the edges of the high pH target area. Well MW-29 is approximately 35 feet from MW-54 and is screened in the shallow zone of the aquifer.

CO<sub>2</sub> injection testing will be conducted to characterize the ROI achieved by different injection rates. The ROI will be measured by monitoring pressure and groundwater pH in several observation wells. The ROI evaluation will be based on an increase in pressure and/or decrease in pH measured in the observation wells. Rebound of the groundwater pH after CO<sub>2</sub> injection also will be monitored.



Groundwater samples will be collected from injection and observation wells to document changes to groundwater chemistry during CO<sub>2</sub> injection and during the expected pH rebound. Pilot testing will be directed toward assessing the effect of the injection rate on the utilization of the CO<sub>2</sub>. In order for CO<sub>2</sub> to neutralize the high pH, the CO<sub>2</sub> must dissolve into the water; a high surface area between the gaseous CO<sub>2</sub> and groundwater will increase mass transfer efficiency. It is expected that high CO<sub>2</sub> injection rates will cause flow channels to form in the saturated zone that would decrease the gas surface area, decreasing dissolution of gas and increasing the flow rate to the vadose zone and ultimately to the atmosphere. As noted in the USACE Engineer Manual In-Situ Air Sparging (USACE, 2013), optimal mass transfer is anticipated to occur at intermediate injection rates, when an appropriate distribution of flow channels forms. The USACE manual indicates that optimal flow occurs when injecting gas at the highest pressure that does not cause fracturing of the formation. Vented CO<sub>2</sub> will be monitored in a vent well completed in the vadose zone and changes in water chemistry will be monitored to estimate changes in total carbonate species. There also is potential for injected CO<sub>2</sub> to migrate outside the observation area due to unknown preferential flow paths or via channels created from excessively high injection pressure. Any gas migration beyond the observation area may not be detected.

#### 4.1 INJECTION AND OBSERVATION WELLS

CO<sub>2</sub> will be injected into well MW-54 during testing, as it is screened at similar depths and soil types as MW-44 outside the barrier wall in the high pH target area. Wells MW-29 and MW-53 are intended to be observation wells. MW-54 will be sealed and pressurized with gaseous CO<sub>2</sub> to inject from the top of the well screen. Observation wells will include existing well MW-29 (which is located approximately 35 feet north of MW-54), MW-53, and four new observation wells to be installed at various distances and depths to monitor the ROI, CO<sub>2</sub> utilization efficiency, and changes in groundwater chemistry (Table 4 and Figure 5). The existing observation wells (MW-53 and MW-29) will be modified by placing a gas-tight cap on the surface casing. All of the observation wells will be monitored for groundwater pH and pressure. Groundwater pH will be measured and recorded in the observation wells using data logging pH probes. If necessary, based on field results, manual pH measurements may be used to replace or supplement the pH probes. The pH and pressure measurements will be used to assess ROI and changes to water chemistry for the pilot test runs.

A vent well is also included in the pilot study design to monitor CO<sub>2</sub> passing through the vadose zone to assist in the assessment of the CO<sub>2</sub> utilization efficiency. The vent well will be equipped with a gas flow meter to monitor the total gas flow through the vent. Drawing P&ID 01, attached to this report, shows the planned design for the injection well, the observation wells, the vent well, and the CO<sub>2</sub> storage and distribution system. Figure 5 shows the locations and layouts of the observation wells and the vent well in relation to MW-54. Table 4 summarizes the approximate depths bgs of the observation wells screens, the depths relative to injection well MW-54, and the approximate spacing



between the wells. The well screen depths may change from the projected depths in the table depending on the soil types and groundwater pH values encountered during well installation. If low pH conditions are encountered during observation well installation, the location may be changed.

The new wells will be drilled by a driller licensed in the State of Washington using a hollow-stem auger rig under the supervision of a Washington State licensed geologist. Prior to drilling, a private utility locator will be hired to locate subsurface utilities in the area of the proposed sample locations. Qualified AMEC staff will work with the site engineers to identify known underground utilities in the area. Sample and well locations will be adjusted in the field to avoid any underground utilities identified and may be adjusted based on lithology encountered during installation. One boring will be continuously logged to a depth of 60 feet bgs or less for lithology and for collection of soil samples. The boring will be backfilled to the target well depth using bentonite chips. Drill cuttings from the well installations will be placed directly into drums and labeled with the contents and date. The drill cuttings will be sampled for proper waste characterization and disposed of in accordance with federal and state laws and regulations. The new wells will be installed using the same design as used in the existing monitoring wells. The sand pack will extend approximately 1 foot above the screen and bentonite chips will be placed from the sand pack to approximately 3-4 feet bgs. The remaining annulus and a heavy-duty flush surface monument will be cemented in place for each well. The new wells will be surveyed for location and elevation. The observation wells will be developed prior to use in the pilot study; recovered groundwater will be treated in the groundwater pretreatment plant prior to discharge to the Seattle sanitary sewer system.

As noted in the CMS Work Plan, it appears that the caustic soda, which is denser than the groundwater; sank to the lower confining layer just below the silt and silty sand layer, and has been in contact with the lower portion of the aquifer. Based on site characterization data, it appears that the sand (SP) and silty sand (ML-SM) layers within the high pH target area outside the barrier wall have the highest pH values. Based on these observations, soil samples will be collected from these two soil units for use in measuring the soil buffering capacity. The soil samples will be collected from the 60-foot boring noted above. The deep boring will be placed in an area of high pH; samples of the SP and the MS-SM soils will be checked for pH in the field prior to sample collection to ensure the soil pH is at 10.5 or greater. If the soil pH is too low, the boring will be abandoned in accordance with regulatory requirements and the boring repeated at a new location. Soil pH will be measured by placing a small amount of soil sample in a container and hand mixing with a 20:1 dilution of deionized water. The pH of the resulting solution will then be measured with a calibrated, portable pH meter.

Drawing P&ID-01 shows the planned configuration of the CO<sub>2</sub> injection system. Pilot study equipment requiring electricity will be located near the groundwater pretreatment building. Tubing to transfer CO<sub>2</sub> will be run to well MW-54 along existing fencing. The liquefied CO<sub>2</sub> storage tank(s), pressure relief



valves, solenoid valve and timer, heater, pressure regulator, and the CO<sub>2</sub> injection flow meter will be located adjacent to the existing groundwater pretreatment building along the north side of the property. Manual shutoff valves and a pressure relief valve also will be located at the wellhead for MW-54. The wellhead for the injection well will be modified to allow the well to be pressurized with CO<sub>2</sub> for injection. A schedule 80 polyvinyl chloride (PVC) adapter will be glued to the existing Schedule 80 well casing to accept threaded PVC fittings. The fittings will support installation of tubing/piping, a pressure indicator, a pressure relief valve, and a shutoff valve, as shown on Drawing P&ID-01. Teflon tape will be used to seal all threaded joints. A similar modification will be made to wells MW-53 and MW-29 to allow the wells to be sealed for pressure measurement. Gas-tight compression fittings will be used to run any tubing or instrument cables into the wells.

The bottom of the vent well screen will be installed a few feet below the groundwater level encountered during installation. The vent will be a 2-inch schedule 80 PVC pipe screened over a 5- to 10-foot interval. The bottom of the screen will extend approximately 2 feet into the lowest expected groundwater elevation, based on available groundwater level data collected inside the barrier wall. The top of the vent will be mounted flush to the existing pavement surface, similar to existing groundwater monitoring wells. A threaded cap will be installed on the vent well casing. The cap will be drilled and threaded to accept a flow meter, pressure gauge and/or pressure logging transducer, and shutoff valve. The flow meter will be a flow totalizer capable of monitoring low flow rates.

The observation wells will be installed with 2-inch schedule 80 PVC screened over a 5- to 10-foot interval. The observation wells will be completed with flush, heavy duty surface monuments. The top of the casing for the observation wells will be threaded so that a threaded pipe cap can be installed to make a gas-tight seal. The pipe cap will be tapped to install a hand valve and pressure gauges and/or pressure logging transducers. A logging pH probe will be installed in each observation well.

The pilot study area, which includes the CO<sub>2</sub> injection well, vent well, and observation wells will be enclosed in temporary fencing to protect equipment and personnel during pilot study injection and monitoring activities. The temporary fencing will be locked with signage warning of pressurized gas lines. The approximate extent of the temporary fencing is shown on Figure 5.

#### 4.2 SOIL BUFFERING CAPACITY

As noted above, in order for target area neutralization to be effective, both groundwater and soil must be neutralized. It is expected that long-term exposure of site soils to high pH groundwater has altered the soil surface chemistry and that the reaction kinetics for soil surface reactions will lead to a slow pH rebound after groundwater is neutralized. The buffering capacity of the soil (the capability of the soil to react with acid) must be neutralized to achieve the objectives for the high pH target area.



Soil buffering capacity has generally been evaluated in the past to assess using lime to increase the pH of soils in the agricultural industry. One published test method added a base to soil sample aliquots at varying concentrations and allowed the aliquots sufficient time to react before measuring the pH of the sample. The final pH, amount of base added, and the mass of the soil provided the lime buffer capacity of the soil (Kissel et al., 2012). Another study focused on determining a method to quickly estimate the lime buffer capacity of a soil by determining a typical reaction time required once a base is added to soils and finding a relationship between the pH measured after a fixed reaction time and the final pH that resulted after the extended reaction time. In that study, a base was added to several soil samples and allowed to react over differing reaction times. The study determined that the required reaction time to progress to equilibrium was five days (Thompson et al., 2010). A third study looked at the addition of an acid to several clays to determine the soil's buffering capacity for the purposes of evaluating the potential for metals to leach from landfills lined with different clays (Phadungchewit, 1990). Phadungchewit took soil samples of each clay type; air dried the samples, and ground the samples to pass a 2-millimeter (mm)sieve. The samples were then separated into 4-gram aliquots and added to plastic tubes. A fixed volume of nitric acid solution (40 milliliters [mL] or a 1:10 soil to solution mixture) was then added to each aliquot. The soil suspension was mixed for 24 hours and centrifuged for 10 minutes and the pH was measured. In each study, various reaction times were provided and the methods varied slightly.

For the purposes of measuring the soil buffering capacity for the pilot study, soil and groundwater samples will be collected during installation of the new observation wells. Two soil types will be tested, based on soil types noted in boring log data from MW-43 and MW-54 and the distribution of high pH observed in the subsurface. As discussed previously, the high pH target area is located within the Shoreline Area in the vicinity of the southwest corner of the site, between 35 and 50 feet bgs. In well MW-44 and in push probes completed during the 2011 shoreline investigation, these depths correspond to a dark grey, poorly graded sand (SP) from approximately 30 to 45 feet bgs and a dark grey silt and silty sand mixture (ML-SM) from 45 to 65 feet bgs. As noted in the CMS Work Plan, it appears that the caustic soda, which is denser than the groundwater; sank to the lower confining layer just below the silt and silty sand layer, and has been in contact with the lower portion of the SP layer and the upper parts of the ML-SM layer. Based on these observations, soil samples will be collected from these two soil units in an area of high pH during new observation well installation. The SP and ML-SM soil samples will be tested for soil buffering capacity.

Water samples collected from MW-54 will be tested for the analytes shown on Table 3. In addition to the alkalinity measurements indicated in the table, a water sample from MW-54 will be used to assess precipitation caused by reducing the groundwater pH with acid. The water sample collected for assessment of precipitation will be collected in a zero headspace container. A sample will be pulled from the sample container and analyzed for total suspended solids prior to any testing of the water.



A 500-mL sample will be taken from the container and will be mixed and titrated with acid down to a pH of 8.0 SU. The sample will be covered, thus reducing interactions with atmospheric conditions, and will be mixed for approximately 24 hours, after which the total suspended solids of the sample will be measured to determine the amount of solids formed from the addition of the acid.

As discussed above, samples of the two soil types expected to be representative of target area soils will be collected from a boring for one of the observation wells. For each soil sample, gravel and other debris larger than 0.25 inch will be separated, as they will likely provide insignificant soil buffering capacity. To ensure that a homogeneous sample is created for each of the two soil samples, each sample will be oven-dried at 70° C to remove moisture from the soil. The soils will be heated until a change in weight of less than 1 percent is observed over an hour of consecutive readings. Once the samples have been effectively dried, each sample will be crushed to pass through a 0.2-mm or smaller sieve to minimize pore diffusion reaction kinetics during soil testing. Each soil sample will then be dried again in an oven at 70° C until two consecutive measurements indicate a total change in mass of 1 percent or less is obtained. The two crushed and dried soil samples will then be tested for soil buffering capacity. Each soil sample will be thoroughly mixed to prepare a homogeneous sample. A series of aliquots will then be prepared for each test; varying doses of acid will be added to each aliquot so that the test series spans the anticipated range of soil buffering capacity.

The testing will be completed in two stages. During the first stage, it will be assumed that the total soil buffering capacity of each soil type will be around 20 times the total alkalinity of the groundwater in equilibrium with the soil, as measured in groundwater samples collected in the region of the soil samples (e.g., a groundwater alkalinity of 1,000 parts per million calcium carbonate equivalents [CaCO<sub>3</sub>] would result in a maximum estimated soil buffering capacity of 2 percent by weight CaCO<sub>3</sub> equivalents). The first stage will test buffering capacity of the soils by dosing 5, 10, 15, 20, and 25 times the groundwater alkalinity by weight, in order to better estimate the maximum buffering capacity to be used in the second stage of testing. Once an upper bound for the acid dose required to neutralize each one of the two soils types is obtained, the two soils will be tested for buffering capacity by spanning the range from a blank dose (only de-ionized water) to the maximum acid dose obtained in the first stage. The samples will be run in duplicate during the final buffering capacity testing to verify reproducibility. During both stages of testing, the aliquots will be mixed with the acid/de-ionized water mixture for an extended reaction time to allow the acid to react with the soil. Residual acid concentrations will enable the quantity of acid that reacted with the soil to be determined, enabling the soil buffering capacity to be calculated. The soil buffering capacity test procedure will be performed for each soil type as described below.



#### Stage 1:

- 1. A total of six aliquots, each approximately equal by weight (e.g., 5 grams [g] each) will be prepared from each crushed, dried soil sample.
- 2. The test series for each soil will include six aliquots being dosed with an acid/de-ionized water mixture at 0 (blank sample), 5, 10, 15, 20, and 25 (acid equivalence as CaCO<sub>3</sub> by mass) times the alkalinity measured in MW-54, as described above.
- 3. Each aliquot will be placed into a sample bottle and mixed with equal volumes of a mixture of de-ionized water and standardized reagent grade sulfuric acid, so that the volume of the water/acid mixture is 10–20 times the soil mass (e.g., 100 mL total volume of a mixture of water and acid for a 5-g soil aliquot).
- 4. The pH will be measured after mixing the blank soil aliquots for 1 hour to verify consistent pH readings and to have a baseline pH.
- 5. Each aliquot will then be continually mixed with a laboratory mixer or shaker or an equivalent method. Consistent with the required reaction time obtained by Thompson et al. (2010), soil samples will be mixed continuously for four days and the pH from all of the six aliquots for each soil type will be measured.
- 6. The samples will then be mixed for another 24 hours and the pH of the al six samples will be measured again, giving the samples five days of reaction time. This process will be repeated on a daily basis until a change of less than 0.1 SU is observed in all six samples for each soil type.

#### Stage 2:

- 1. A total of 32 aliquots, each approximately equal by weight (e.g., 5 g each) will be prepared from each crushed, dried soil sample.
- 2. Twenty-one of the soil sample aliquots will be prepared for the primary soil buffering capacity testing. The test series will include one blank sample where no acid is added and 20 aliquots with equal incremental amounts of acid up to the maximum estimated soil buffering capacity as determined in Stage 1 of testing.
- 3. Eleven aliquots will be prepared as a duplicate of the primary test series. The duplicate series will include one blank sample and duplicates ranging from 10 to 100 percent of the maximum estimated soil buffering capacity in increments of 10 percent.
- 4. Each aliquot will be placed into a sample bottle and mixed with the equal volumes of deionized water or a mixture of deionized water and standardized reagent grade sulfuric acid, so that the volume of the water/acid mixture is 10–20 times the soil mass (e.g., 100 mL total volume of a mixture of water and acid for a 5-g soil aliquot). For the primary and duplicate test series, each aliquot will be dosed with standardized reagent grade sulfuric acid to evenly span the estimated range of soil buffering capacity, with aliquots dosed from 0 to 100 percent of the measured maximum buffering capacity in Stage 1.
- 5. The pH will be measured after mixing for the blank soil aliquots for one hour to verify consistent pH readings and to have a baseline pH.



- 6. Each aliquot will then be continually mixed with a laboratory mixer or shaker or an equivalent method. Consistent with the required reaction time obtained by Thompson et al. (2010), soil samples will be mixed continuously for four days and the pH from five of the 21 aliquots for the primary series for each soil type will be measured at the 0, 25, 50, 75 and 100 percent acid-dosed containers.
- 7. The samples will then be mixed for another 24 hours and the pH of the same five samples will be measured again, giving the samples five days of reaction time. This process will be repeated on a daily basis until a change of less than 0.1 SU is observed in all five samples for each soil type.

The final pH measurement in each of the aliquots and the acid doses will be evaluated to develop a buffering capacity curve for the soil sample. The duplicate tests will be used to assess the reproducibility of the tests.

The buffering capacity of the soil will identify the total acid dose needed to fully neutralize the soil. This information is needed to estimate the total amount of CO<sub>2</sub> that must be delivered by an injection system. The measured soil buffering capacity will not provide information regarding the amount of time it would take for site soil to be neutralized. The rate of soil neutralization must be assessed in the field during pilot testing.

#### 4.3 PILOT STUDY TESTING AND MONITORING PLAN

The pilot study test plan is designed to address the objectives discussed in Section 3. MW-54 is reasonably representative of the depths and conditions in the high pH target area and will be used as the injection well to deliver CO<sub>2</sub> to the subsurface adjacent to the well. Testing will consist of injecting gaseous CO<sub>2</sub> into the injection well and observing changes in pressure, pH, and groundwater chemistry in the observation wells. Four phases of testing are planned: the initial phase will be directed toward assessing the effect of the injection rate on the ROI, the second phase will assess the initial pH rebound, the third phase will focus on injection at the optimal rate to assess anticipated operating conditions, and the final phase will assess long-term pH rebound.

A range of injection pressures and the corresponding injection flow rates will be tested in the initial series of injection test runs to assess the effect of flow rate on ROI and CO<sub>2</sub> venting rates. The test runs will start at low injection pressure and proceed to the maximum injection pressure. Each test run will include a period with no CO<sub>2</sub> injection to allow the CO<sub>2</sub> to dissolve in the groundwater prior to subsequent injection tests. After completing the initial series of test runs, the second phase will consist of an extended monitoring period to evaluate pH rebound and changes in groundwater chemistry. After rebound is judged to be sufficient, injection testing will resume at the optimal flow rate determined in the initial injection testing runs. The final phase will assess the pH rebound rate and collect further information on changes in groundwater chemistry. Prior to initial injection testing,



baseline groundwater chemistry samples will be collected from wells MW-53, MW-54, MW-29, the vent well, and the observation wells to establish baseline water chemistry conditions. Each sample will be analyzed for the parameters shown in Table 3.

### 4.3.1 Phase 1 Testing: Evaluation of Injection Pressure and Flow Rates

As noted above, the initial phase of injection testing will evaluate a range of injection rates and the resulting effect on the ROI for the injection well. According to the *In-Situ Air Sparging* Engineer Manual (USACE, 2013); injection pressures should range between the minimum injection pressure, (i.e., the sum of the hydrostatic pressure at the top of the well screen and the formation entry pressure) and the maximum injection pressure that does not cause fracturing of the subsurface soils. For the site, the minimum pressure to inject into MW-54 is approximately 15 pounds per square inch gauge (psig) and the maximum injection pressure (including a safety factor of 40 percent) is approximately 21 psig (calculations included in Attachment 1). Initial injection testing will asses this pressure range.

Each injection pressure tested will have a corresponding injection flow rate that depends on well and aquifer characteristics. Per the USACE manual, the pilot test injection system should be able to deliver a flow rate of up to 3 standard cubic feet per minute. Injection pressures for CO<sub>2</sub> will be controlled by manually adjusting the pressure regulator shown on Drawing P&ID-01. The injection well will be pressurized with CO<sub>2</sub> by opening the primary injection valve (HV-2) and the injection well inlet valve (HV-3) as shown on Drawing P&ID-01. The CO<sub>2</sub> injection pressure will be adjusted by setting the pressure reducing regulator (PR-1), which will maintain a constant injection pressure. The injection pressure will be adjusted incrementally from 15 psig up to 21 psig in 1 psig increments and the flow rate for each test run, as measured by FM-1, will indicate the flow rate and also totalize flow.

As shown on Drawing P&ID-01, each observation well will include a pressure indicator (either handheld or a transducer and data logger) that will be used to measure pressure in the well to support evaluation of the ROI for the injection pressure being tested. It is anticipated that the injection pressure in the observation wells located within the ROI will increase after injection startup and will approach a steady state. As a result, the pressure measurements being logged in the observation wells will be used as one indicator of the ROI. Each observation well will also be equipped with a pH probe and data logger that will monitor groundwater pH in the well. The groundwater pH data in the observation wells will be used to support evaluation of the ROI. Once a steady state or slight decline in pressure is observed in the observation wells, the CO<sub>2</sub> feed to the injection well will be closed off and the system will be turned off for 24 hours to allow excess gas trapped in the aquifer to dissipate. Pressure will be logged during this period to determine how long it takes for the pressure to decrease back down to a steady-state value, implying that groundwater mounding created by gas injection has



dissipated. It is assumed that at least eight hours of injection time will be provided for each injection test run, but actual time will depend on field conditions.

At the conclusion of each injection pressure test run (after pressure in the observation wells has dissipated), samples will be collected from each observation well and analyzed in the field for pH and in the laboratory for total alkalinity and dissolved silicon; these results will be used to assess the ROI for the injection pressure tested and to identify any induced changes to water chemistry. The injection pressure, injection flow rate, and other observations from each test run will be logged and used to evaluate the ROI. In addition, pH will be logged from the pilot study observation wells during and between test runs. The vent well will be monitored for gas flow from the vadose zone. Measurements from the vent gas flow meter and the groundwater alkalinity and total silicon measurements will be used to assess the CO<sub>2</sub> utilization efficiency.

### 4.3.2 Phase 2 Testing: pH and Water Chemistry Monitoring

Upon completion of the Phase 1 injection testing, the pH rebound caused by soil buffering capacity will be assessed by collecting groundwater samples from the pilot study observation wells to monitor changes in groundwater chemistry resulting from CO<sub>2</sub> injection and continuing to monitor pH in the observation wells using the pH probe/data loggers. The groundwater samples will be analyzed for all of the parameters shown in Table 3. These data will be used as appropriate to support Visual MINTEQ modeling runs to assess changes in groundwater chemistry. Data from the pH probes will be used to assess the rate of pH rebound and to determine when rebound monitoring should be terminated to proceed with Phase 3 injection testing.

During the Phase 2 monitoring period, the data collected during the Phase 1 initial injection testing will be evaluated. These results will be used to finalize plans for the full-scale injection testing to be conducted in Phase 3. The optimal injection flow rate will be identified from the results of the Phase 1 testing. The end of the monitoring period and the beginning of the full-scale injection simulation period will be determined by the pH rebound, as measured in MW-53. When the pH in MW-53 increases to 10 SU or more, Phase 3 of the pilot study testing will be initiated.

### 4.3.3 Phase 3 Testing: Full Scale Injection Simulation

Phase 3 will consist of full-scale injection simulations at the optimum injection rate identified from Phase 1 testing. This simulation will include testing pulse injections into MW-54 to promote mixing in the injection zone. Phase 3 testing will be done at the target pressure and flow rate determined from the Phase 1 injection startup testing outlined in Section 4.3.1. The Phase 1 observation well pressure data (both the period of increasing pressure during initial injection and the decreasing pressure later in the test run) will be used to design the injection pulsing periods. The goal of the injections during simulations will be to create conditions where the groundwater will continually mix due to cycling



groundwater mounding. This will be done by cycling CO<sub>2</sub> flow on and off using a solenoid valve connected to an on/off timer set to the appropriate cycles (see Drawing P&ID-01). Injection pressure for MW-54 will be monitored throughout this phase of testing to assess changes in injection pressure for maintaining the target CO<sub>2</sub> flow rate. Pressures measured in MW-53 and the other observation wells will be used to fine-tune injection cycling during the duration of Phase 3. Injection cycling will continue in MW-54 during Phase 3 testing until the pH measured in MW-53 reaches 5.0 SU, at which point the injection flow will be stopped by closing the pressure regulator manually

During injections for the full-scale simulation; the vent well flow will be monitored and pH will be logged for the duration of the testing. In addition, pressure will be logged during the simulation testing. A complete groundwater chemistry analysis will be performed for all of the pilot study wells immediately after injections have ceased, using the parameters shown on Table 3.

### 4.3.4 Phase 4 Testing: Rebound Monitoring

Upon completion of the Phase 3 full-scale injection testing, a second period of pH rebound monitoring will begin. During this rebound monitoring period, pH will be monitored with data loggers in the observation wells. Monitoring will continue until the pH of the groundwater in MW-53 has increased to 10.0 SU or until pH monitoring data indicate that it is not likely the pH of MW-53 will rebound to this pH level in a reasonable time period as discussed with the United States Environmental Protection Agency (EPA) during the monitoring period. Pressure in the pilot study observation wells will also be monitored after injections have ceased, in order to evaluate how mounding effects change after an extended injection period. At the end of Phase 4, samples will be collected from the observation wells and analyzed for the parameters on Table 3 to assess final changes to groundwater chemistry.

### 4.4 SAMPLING

Soil samples of the two primary soil types present in the target area will be collected during the installation of new observation wells for the CO<sub>2</sub> injection pilot study. The boring for collection of soil samples will be done in an area with a high pH (greater than 10.5 SU). After completion of the new observation wells, groundwater samples will be collected from MW-29, MW-53, MW-54, and the new observation wells to establish baseline conditions prior to initiating CO<sub>2</sub> injection. Samples will be collected as described in Section 4.3 for the CO<sub>2</sub> injection runs and prior to pH rebound monitoring to compare neutralized water analyses to the baseline lab results. All soil and groundwater samples will be collected in accordance with the 2006 soil sampling QAPP (Geomatrix, 2006) or the groundwater monitoring QAPP (URS, 2002).



### 4.5 PERMITTING

Subsurface injection permits will be obtained from the Washington State Department of Ecology prior to implementing CO<sub>2</sub> injections for the pilot study. Start cards will be obtained for installation of the observation and vent wells. No other permits will be needed to conduct the pilot study.



#### 5.0 REPORTING

During performance monitoring of the CO<sub>2</sub> injection pilot study, progress reports will be prepared and submitted to EPA on a monthly basis with the current monthly progress reports. The monthly reports will include tables of the data collected or received during the preceding month and a summary of pilot study activities planned for the next reporting month. Significant issues or findings, if any, will be described in the progress reports. The monthly data summary will include the quantity of CO<sub>2</sub> injected, the duration of active injection and/or pH rebound evaluation, pH monitoring data, and typical injection pressures.

After completing CO<sub>2</sub> injection and pH rebound runs, and obtaining all resulting analytical data as described above, a summary Pilot Study Report documenting pilot study field methods, observations, results, conclusions, and recommendations will be prepared and submitted to the EPA. Deviations, if any, from this work plan will also be documented in the Pilot Study Report. Data results will be summarized in tables and plots as appropriate. A final recommendation for the applicability and feasibility of CO<sub>2</sub> injections to neutralize soil and groundwater within the high pH target area will be presented in the report.



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### 6.0 SCHEDULE

A complete project schedule is included in the Section 10 of the CMS. From the project schedule, it is projected that the CO<sub>2</sub> injection pilot study will take approximately 37 weeks after EPA approval of the CMS Work Plan. The actual schedule may be changed, if appropriate based on information collected during performance of the pilot study. Updates to the pilot study schedule will be included in the monthly progress reports.



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**TABLES** 



#### TABLE 1

### **GROUNDWATER pH MEASUREMENTS** 1

Former Rhone-Poulenc Site Tukwila, WA

	рН	рН	pH
	(min)	(avg)	(max) <sup>2</sup>
Monitoring Well <sup>3,4</sup>	(su)	(SU)	(SU)
DM-7 <sup>5</sup>			6.55
DM-8	6.56	6.69	6.85
H-10 <sup>5</sup>			6.42
MW-12 <sup>5</sup>			6.47
MW-17 <sup>5</sup>	6.41	6.60	6.89
MW-20 <sup>5</sup>			6.56
MW-27 <sup>5</sup>	9.03	9.40	10.16
MW-28 <sup>5</sup>	10.33	10.61	11.28
MW-29 <sup>5</sup>	6.43	6.59	6.78
MW-51 <sup>5</sup>			6.84
MW-52 <sup>5</sup>			7.92
MW-53 <sup>5,6</sup>	7.48		10.79
MW-54 <sup>5,6</sup>	9.71		10.52
MW-38R	6.65	6.73	6.86
MW-39	7.24	7.36	7.64
MW-40	7.66	7.80	7.92
MW-41	8.60	9.73	10.11
MW-42	7.52	7.61	7.66
MW-43	9.02	10.53	11.14
MW-44	9.05	10.50	11.26
MW-45	7.03	7.40	7.84
MW-46	6.29	6.42	6.69
EX-3 <sup>5</sup>	6.30	6.63	6.90
Push Probe <sup>7</sup>			
SL-07			8.86
SL-08			9.84
SL-09			10.24
SL-10			10.27
SL-11			10.62
SL-12			11.5
SL-13			10.68
SL-14			10.9
SL-15			9.82

#### Notes

- 1. **Bold** pH values are above the acceptable range for the Duwamish Waterway.
- Maximum acceptable pH is 8.5, based on Washington State Department of Ecology surface water criteria for the Duwamish Waterway.
- 3. Monitoring well pH data includes all data from 2008-present.
- For locations with fewer than three analyses, no average is calculated and only a min and max are shown. For locations with only one analysis, the result is presented as the maximum.
- 5. Analytical results includes nonroutine samples collected in June 2014.
- 6. Analytical results include nonroutine samples collected in March 2014.
- Push probe data are from the Shoreline Soil and Groundwater Characterization Data Report (AMEC, 2012). The data are the maximum for the probe locations.

#### <u>Abbreviations</u>

avg = average

max = masimum

 $\min = \min \max$ 

SU = standard unit



#### TABLE 2

### PILOT STUDY WELLS pH TOTAL ALKALINITY AND TOTAL DISSOLVED SILICON

Former Rhone-Poulenc Site Tukwila, WA

Well <sup>1,2,3</sup>	pH (min) (SU)	pH (avg) (SU)	pH (max) (SU)	Total Alkalinity (min) (mg/L CaCO <sub>3</sub> )	Total Alkalinity (avg) (mg/L CaCO₃)	Total Alkalinity (max) (mg/L CaCO <sub>3</sub> )	Silicon (min) (mg/L)	Silicon (avg) (mg/L)	Silicon (max) (mg/L)
<b>HCIM Area</b>	HCIM Area Wells								
MW-29	6.43	6.59	6.78	234	280	427	40	44	46
MW-53	7.48		10.79		-	1,000			224
MW-54	9.71		10.52			1,030			3,870
Shoreline A	Shoreline Area Wells								
MW-43	9.02	10.53	11.14	1,800	1,933	2,020	214	325	391
MW-44	9.05	10.50	11.26	2,540	2,718	2,980	628	643	667

#### Notes

- 1. For wells with less than three sample results, no average is calculated and only a min and max are shown. For wells with only one analysis, the result is presented as the maximum.
- 2. pH data are for groundwater monitoring and sampling from March 2008 to present.
- 3. Alkalinity and silicon data shown includes all 2005 data and samples collected for MW-29, MW-53 and MW-54 in 2014. No routine samples were collected for MW-53 or MW-54 for these analyses after 2005.

#### **Abbreviations**

avg = average

CaCO<sub>3</sub> = calcium carbonate equivalents

max = masimum

min = minimum

mg/L = milligrams per liter

SU = standard unit



#### TABLE 3

#### PERFORMANCE MONITORING ROUND 28 WATER CHEMISTRY DATA<sup>1</sup>

Former Rhone-Poulenc Site Tukwila, WA

								Total				Total Metals						
Well ID	Laboratory pH <sup>2</sup>	Sodium (mg/L)	Potassium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Cl <sup>-</sup> (mg/L)	Silicon (mg/L)	Alkalinity (mg/L CaCO <sub>3</sub> )	SO <sub>4</sub> <sup>2-</sup> (mg/L)	HS <sup>-</sup> (mg/L)	NO <sub>2</sub> <sup>2-</sup> (mg-N/L)	Iron (mg/L)	Manganese (mg/L)	Vanadium (mg/L)	Chromium (mg/L)	Aluminum (mg/L)	T <sub>P</sub> (mg/L)	T <sub>N</sub> (mg/L)
MW-28	10.58	476	26.3	4.38	0.45	12.5	320	1460	122	4.01	0.125	5.6	0.178	0.047	0.010	0.89	2.30	0.125
MW-28 Dup	10.58	499	27.3	3.82	0.3	12.5	324	1460	120	4.39	0.125	3.8	0.118	0.044	0.010	0.88	2.49	0.125
MW-38	6.72	107	5	17.9	18.7	35.9	30.5	342	165	0.05	0.05	21.5	1.060	0.032	0.007	0.37	1.95	0.05
MW-39	7.58	533	20.3	5.45	9.41	531	22.1	682	263	0.05	0.100	3.1	0.062	0.025	0.010	0.89	13.8	0.100
DM-5	7.34	509	5.3	13.8	10.8	53.2	24	1430	576	0.05	0.25	10.6	0.147	0.457	0.112	3.06	18.6	0.25
MW-27	10.07	1440	63.4	2.36	0.34	10	271	2400	977	4.1	0.100	0.8	0.017	0.050	0.003	2.11	1.36	0.10
MW-29	6.68	63.6	3.6	19.7	10.1	10.0	43.5	234	65	0.050	0.100	27.0	1.810	0.003	0.003	0.15	0.932	0.47
MW-42	7.71	521	20	7.72	9.21	546	18.6	696	98	0.050	0.125	1.6	0.092	0.031	0.013	6.39	19.0	1.26
DM-8	6.96	330	8.0	19.2	9.11	232	25.7	256	435	0.050	0.125	13.0	1.430	0.059	0.009	0.89	6.24	0.125
MW-41	10.07	782	8.0	10.9	11.3	747	123	1300	400	22.4	0.25	2.0	0.071	0.314	0.072	1.37	7.03	0.25
MW-41 Dup	10.11	875	8.4	11.5	11.1	724	126	1330	383	19	0.25	2.1	0.071	0.359	0.076	1.44	8.32	0.25
MW-40	7.75	1710	58.7	62.6	149	3650	20.2	686	102	1.18	0.025	0.1	0.118	0.008	0.003	0.49	15.00	0.025
MW-17	7.17	538	6.1	26.6	5.18	25	21.2	1390	455	0.37	0.25	9.0	1.400	0.486	0.071	2.65	18.7	0.987
MW-43	10.34	939	18.9	11	0.32	411	336	2020	451	7.5	0.25	1.8	0.010	0.390	0.074	1.21	29.6	0.526
MW-44 <sup>3</sup>	10.98	859	8.3	8.44	1.36	74.3	668	2980	161	14.5	0.125	6.8	0.196	0.310	0.033	1.21	1.84	0.125
MW-45	7.67	366	15.3	4.95	5.31	359	19.9	662	94	0.05	0.125	2.4	0.107	0.030	0.010	3.97	17.4	0.125
MW-46	6.5	219	13.9	58.1	37.7	365	26.3	391	27	0.05	0.05	34.0	1.240	0.011	0.003	0.05	1.08	0.05
EX-3	6.82	197	7.1	13.7	12.8	12.5	27.5	474	233	0.05	0.125	26.3	1.070	0.046	0.009	0.1	2.92	0.13
B1A	6.31	32.7	3.3	9.84	5.48	2.5	18.3	112	28	0.05	0.005	8.9	0.250	0.002	0.003	0.12	0.162	0.011

#### Notes:

- 1. Round 28 samping event data for samples collected June 15, 2005.
- 2. Laboratory pH was measured during alkalinity analysis for each sample.
- 3. Bold values were used in equilibrium model.

#### Abbreviations:

 $CaCO_3$  = calcium carbonate equivalents

Dup = Duplicate sample

mg/L = milligrams per liter

mg-N/L = milligrams as nitrogen per liter

T<sub>N</sub> = Total nitrogen

 $T_P$  = Total phosphorous



**TABLE 4** 

### PILOT STUDY AREA AND HIGH pH SHORELINE AREA WELL DETAILS

Former Rhone-Poulenc Site Tukwila, WA

Well	Depth of Well <sup>1</sup> (feet bgs)	Screen Length <sup>2</sup> (feet)	Well Diameter (inches)	Distance from MW-54 (feet)	Vertical Distance from MW-54 Screen <sup>3</sup> (feet)	Distance from MW-53 (feet)	Vertical Distance from MW-53 Screen <sup>4</sup> (feet)			
Shoreline	Area High pH W	/ells								
MW-43	61.3	10	2	37	-11.3	37	-31.3			
MW-44	41.6	10	2	37	8.4	37	-11.6			
Pilot Study	Pilot Study Injection Wells									
MW-54	60	10	2			8	-30			
Pilot Study	Pilot Study Observation Wells									
IM-1 <sup>5</sup>	40	5	2	10	10	8	-10			
IM-2 <sup>5</sup>	30	5	2	12	20	10	0			
IM-3 <sup>5</sup>	25	5	2	15	25	13	5			
MW-29	21.1	15	2	35	28.9	37	8.9			
MW-53	40	10	2	8	10					
Vent <sup>5</sup>	10	5	2	4	40	4	20			

#### Notes:

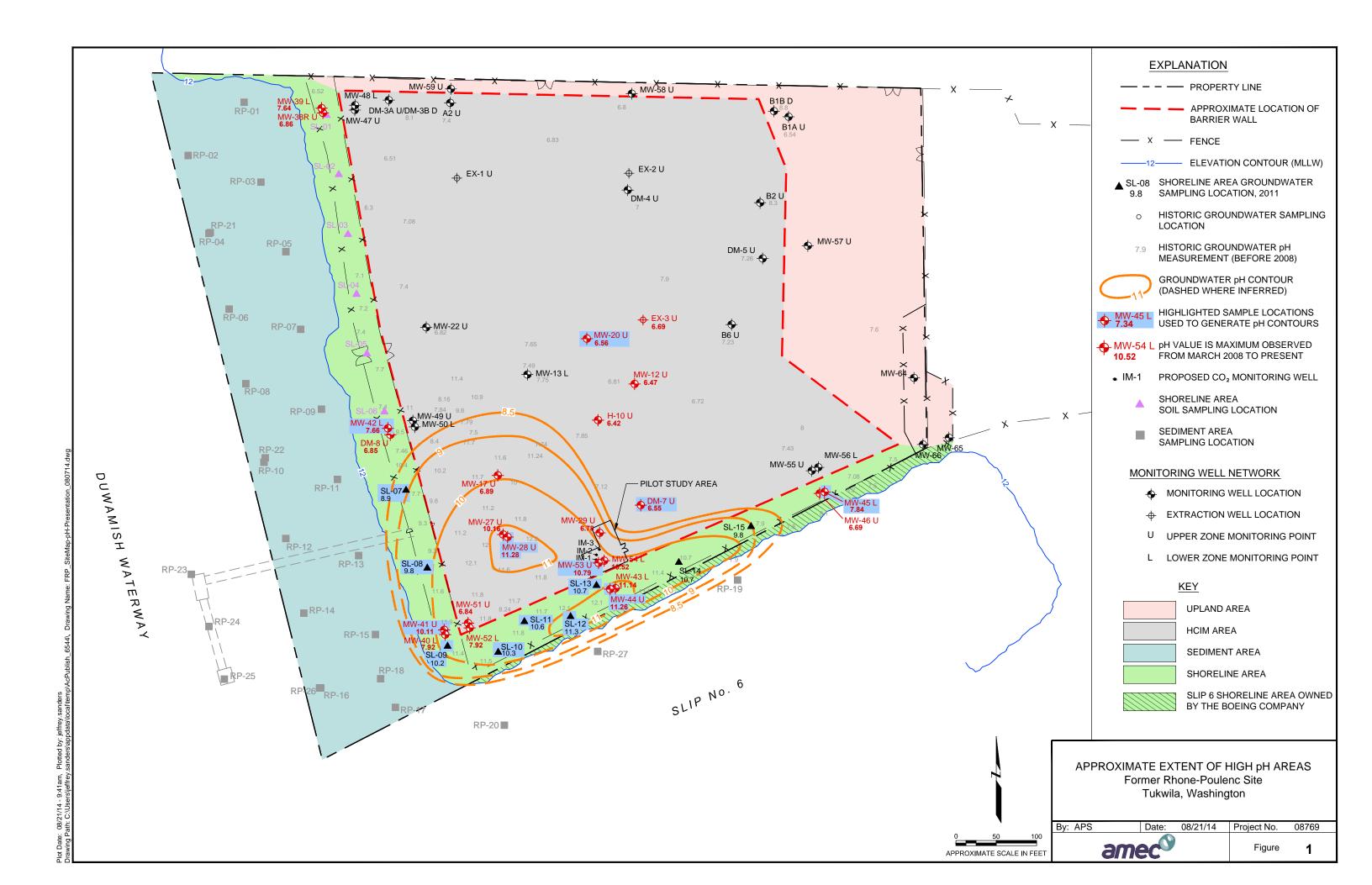
- 1. Depth to bottom of well is the total depth from the surface to the bottom of the well's screen.
- 2. Screen length is the total length of the screen.
- 3. Distance above well screen is the distance from the top of the MW-54 well screen to the bottom of the designated well. Negative values mean the bottom of the designated well is deeper than the top of the MW-54 screen.
- 4. Distance above well screen is the distance from the top of the MW-53 well screen to the bottom of the well being compared. Negative values mean that the bottom of the well being compared is deeper than the top of the screen for MW-53.
- 5. Depth of wells and vent may be changed in the field depending on subsurface geology and chemistry.

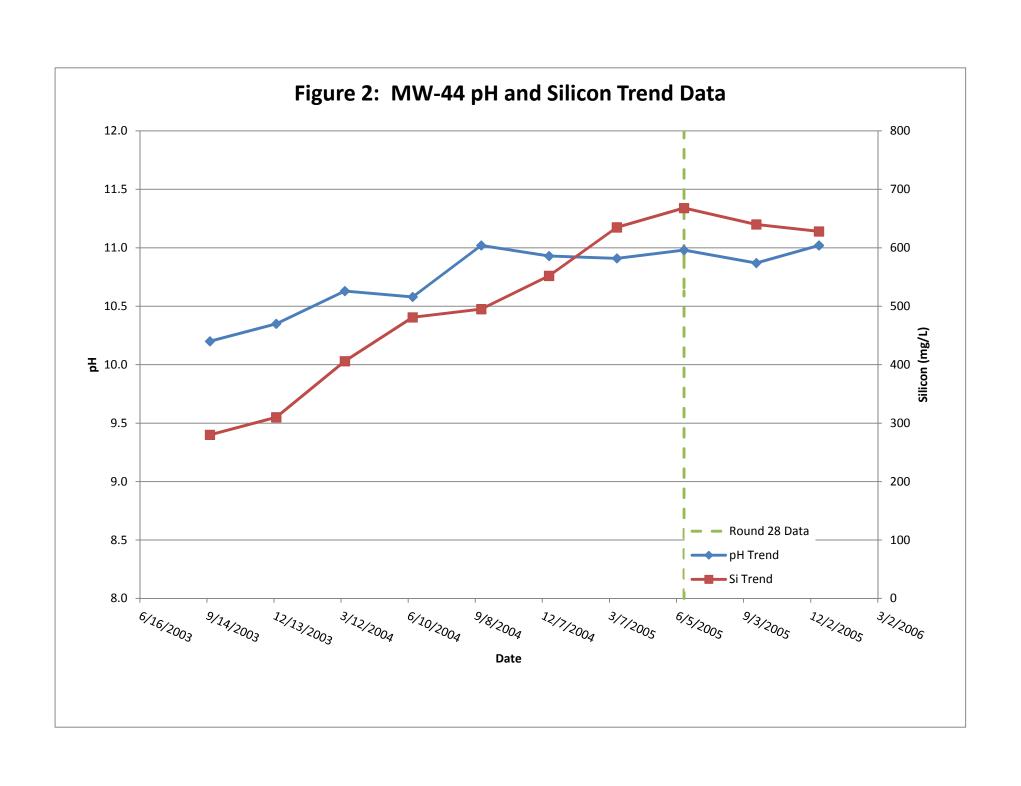
#### Abbreviations:

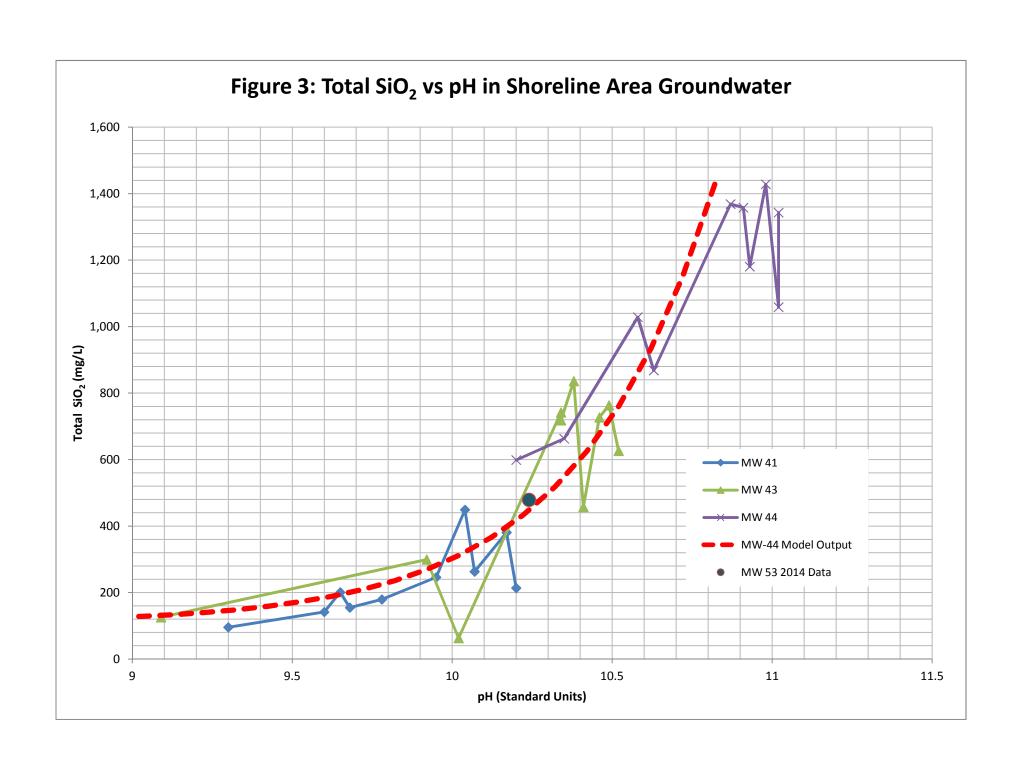
bgs = below ground surface

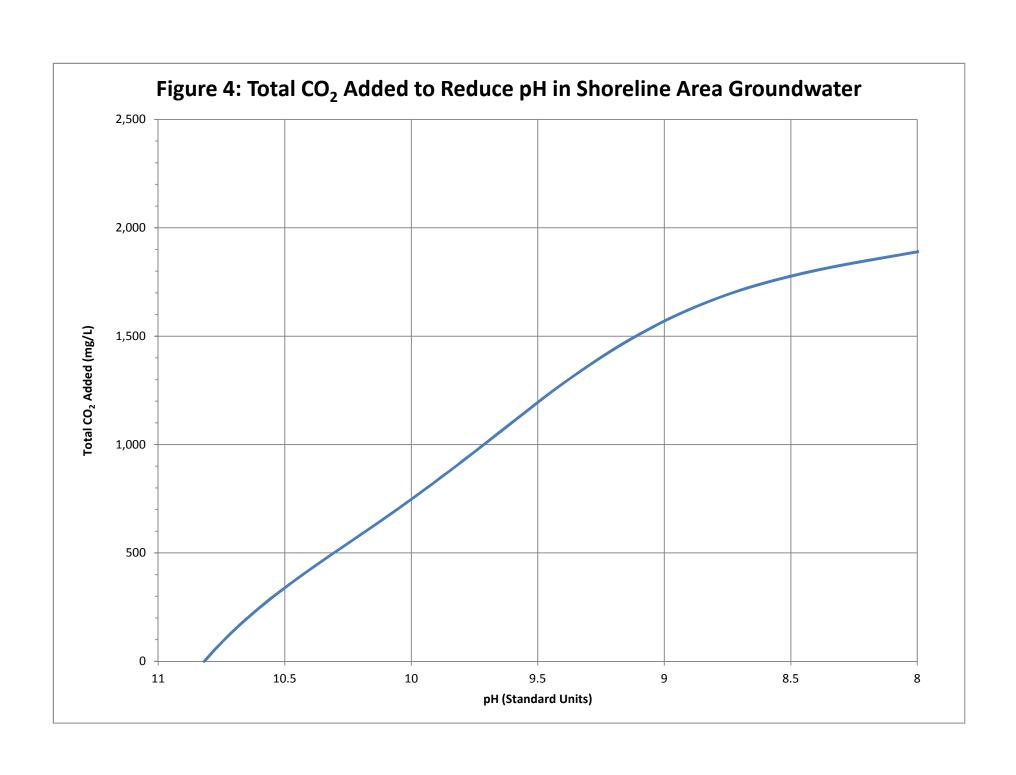


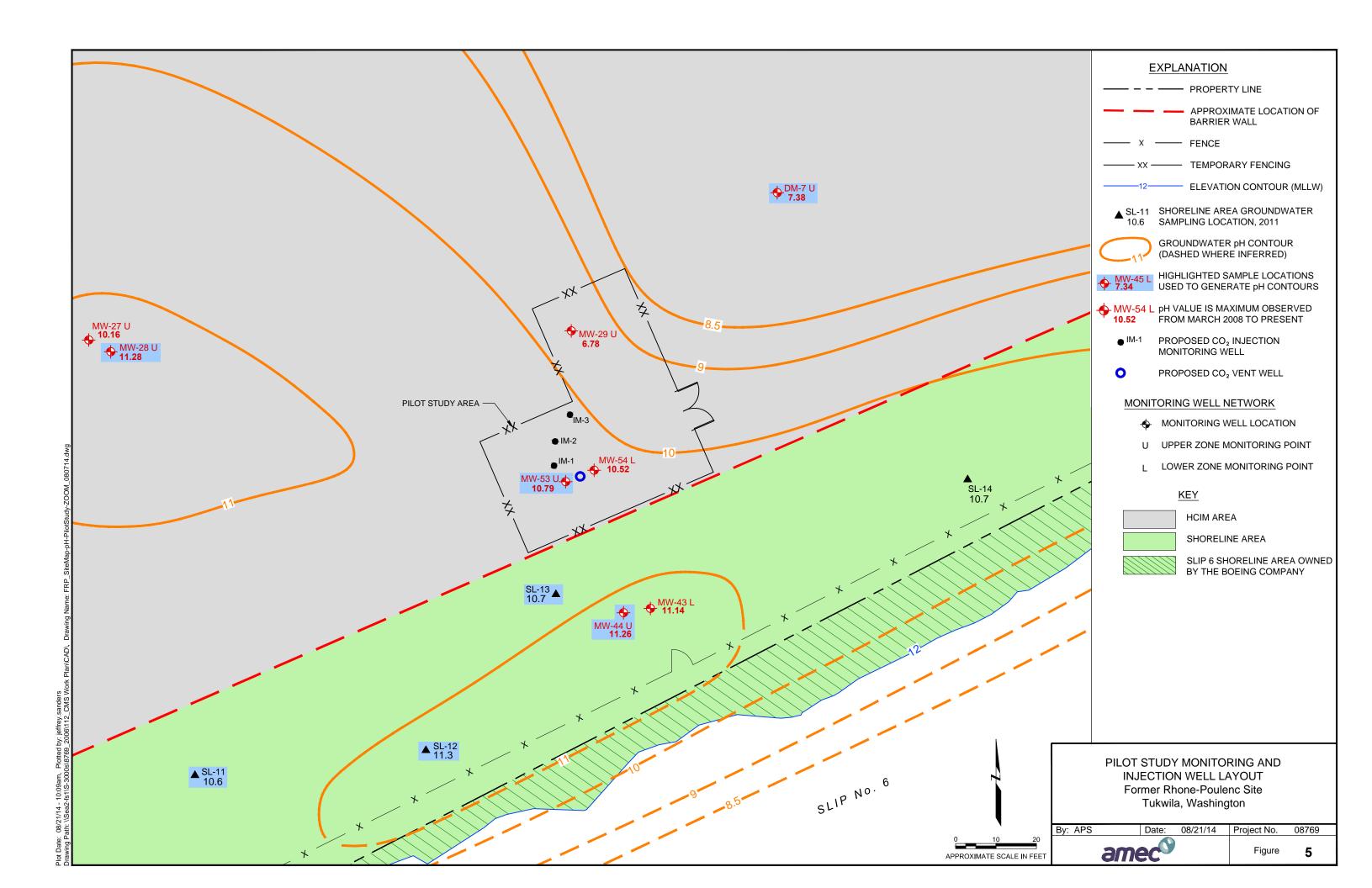
**FIGURES** 





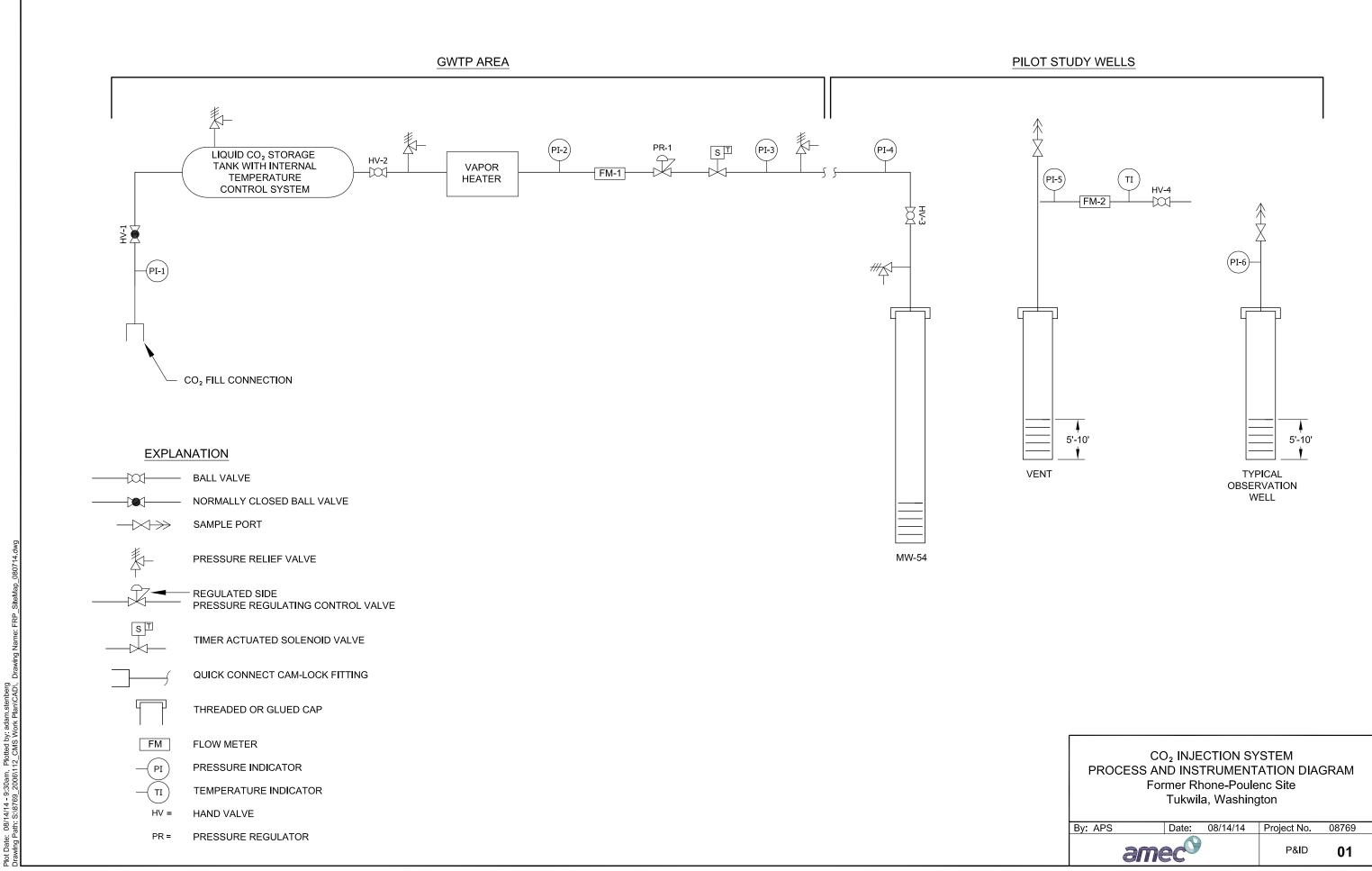








**DRAWINGS** 



P&ID

01



# ATTACHMENT 1

Calculations for CO<sub>2</sub> Injection Pressures

Client: Container Properties	_ Sheet _ 1 _ Of _ 1
Project: FRP CMS WP	Sheet1 of1 anec
Data For: CO2 Pilot Study WP	
Prepared By: CDH Checked By: LMM	File No:
Note: This form must be used for project calculations and o	priginal filed in project files
Purpose:	
	essures for the COO Pilot Study Work Plan (PSWP).
from the guidance document "In- Situ	Air Spanging: Engineer Manual" by the US Army
Core of Engineers CUSACOE) published	31 December 2013 (USACO €, 2013); The
naxmum injection pressure or over burden aquifor is:	pressure to prevent fracture formation in the
Overburden pressure = Pab = Pressure soil 60	olumn + Preside cate column = PSC + PWC
where Puc = (depth up well secon - depth to water	table ) (3.9, words) (0) (9.8 KN/m3)
and PSC = (death mp well screen ) (5.9.50	
Assumptions:	
Soil 56 = 5.9. 201 = 2.5 ; Poresity	1 = 0 = 0.5 (conservative estimate)
	Let som = down = 50 A for MU-54 depth to valor take - dux = 15.
Puc = (dows - dut) (s.g. water) (0) (9.8	3 KPa) = (35 A) (1.0)(0.5)(9.8 KPa) = 50.3 KPa=7.6ps
Pac = (dows) (5. g. 50:1) (1-6) (9.8 kPa) = (	504) (0.3048 m/4) (2.5) (0.5) (9.8 kg) = 184.8 kga = 26.8 gs
Pab = Pac + Puc = 26.8 psig + 7.6 psig =	34,4 psig
In accordance with (USACOE, 2013),	max injection pressure = Pob x Safety factor (20-40%)=Po
	The second secon
* Proux = Pob x 0.6 = 34.4 psig x 0.6	= 20.6 eng = 121 ps/a
from (USACOE, 2013), the minimum	injection pressure (Poin) is the pressure sure (Ph) and the aquifor formation entry
required to overcome the hydrostatic pres	sure (Ph) and the aquifor formation edgy
Poin = Pn + Pent = (dus - dut	XhuXg) + Pent
Assumptions:	
d+us= 50# ; due= 15# ; (Pw)	
Post = 0.44 psig for fine to need so	nd (USACOE, 2013 table 2-2)

\* Pria = (354) (0.43 psi/4 H20) + 0.44 psig = 15.49 psig = 15 psig